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A Primer of Wood Preservation.

The disquieting manner in which good wood has grown scarcer, its price has increased and the use of unsuitable timber has spread, is something with which all engineers and architects are familiar. The reckless destruction of forests to supply the highest-grade timber for all sorts of purposes, whether such high grades were necessary or not, has brought about the inevitable result. In a short time we shall be confronted by the same conditions that face the builders of Europe, but will be without their knowledge of methods of meeting the situation where timber must be employed, no substitutes being possible. The destruction of the American forests can be checked only in two ways; by the practice of forestry principles on a great scale, which is slowly coming into prominence as a national economical necessity, and by prolonging the life of timber in service by some method of treatment. A large part of the wood used in the country cannot be treated in any manner on account of the use made of it, but there is a considerable portion to which it is desirable to give a longer life in this way. The trouble is that so very few people know anything about the methods of preserving timber for minor uses; during the last few years these methods have been developed until there is no longer any excuse for the use of untreated timber, except in a very limited amount, in situations where treated timber is more advantageous.

Methods of preservation must be varied for different localities and different kinds of wood, but there are certain general principles involved in the different processes which are readily understood. These are outlined in an excellent manner by Mr. W. F. Sherfesee, of the U. S. Forest Service, in a bulletin entitled "A Primer of Wood Preservation," just issued by the Department of Agriculture. The importance of the subject is so great, not only to engineers and architects, but also to all who are interested in national economics, that special attention is called to this little outline of the subject. It explains what decay is and how decay can be retarded by seasoning and by chemical impregnation, it outlines the preservatives and processes used in the United States, forecasts the tendency of wood preservation in our country, and closes with a forceful demonstration of the saving in dollars and cents which follows from the practice of rational wood preservation. It is shown that by treating loblolly pine fence posts there is a saving to the farmer each year for every mile of fence of a sum equivalent to the interest on $220. The treatment of a loblolly pine tie is equivalent to the saving of an investment of $1,175 per mile of track, or a little over 2 cents per tie per year. In the same way a considerable saving on poles for telegraph and telephone companies and like purposes can be made by subjecting them to some preservative treatment. Moreover, this treatment permits the use of grades of timber which are employed only with great reluctance in an untreated condition, and opens up a use for species which can probably furnish supplies for many years to come if they are not wasted with the same carelessness that has marked much of the cutting done in the past.

Forestry experts have been warning us for a number of years that at the present rate of consumption structural timber will be practically exhausted in the United States in a short time unless great changes are made in its methods of use. Fence posts, railroad ties, line poles and mine timbers exhaust an enormous amount of timber annually and form such a serious drain on our forests and wood lots that the little primer explaining briefly methods of checking the wasteful part of this drain should have a wide circulation among those who are using timber for the purposes mentioned. It shows that by simple methods of treatment not only is it possible to extend the life of grades of wood now used for such purposes, but more species can be utilized and millions of feet of timber killed by insects or fire in the West can be rendered useful by preservative processes. In the South the cheap and abundant loblolly pine, one of the easiest of all woods to treat, can be made to take the place of the high-grade long leaf pine for many purposes if it is properly prepared for them. Black and tupelo gums and other little-used woods have a new and increasing importance because of the possibility of preserving them from decay at small cost. In the Northeastern and Great Lake States the tamarack, hemlock, beech, birch, maple and the red and black oaks are being subjected to treatment which permits them to replace the fast-diminishing white oak and cedar, while in the Mississippi Valley the fence-post problem is being greatly relieved by treating cottonwood, willow and elm by inexpensive preservative methods. The Department of Agriculture has rendered an important service to architecture and engineering by the preparation and distribution of this valuable little primer, and the readers of The Engineering Record will help forward an important national economical reform by referring those who are now using timber wastefully to the economies they can obtain by following the suggestions of this pamphlet.

The Minor Transportation Problem.

The recent activity directed toward the development of waterways by the Government, and the steady movement for good roads bear witness to the genuine importance of improving the available means of transportation. To the average man the word "transportation" simply brings up the image of a railway train. Transportation in this country has, in fact, meant railroads built here, there and everywhere, sometimes in the single-minded endeavor to market the largest possible bond issue. In point of fact the whole structure of modern society has been held to rest upon the doctrine of charging what the traffic will bear. Cheap transportation is, of course, a good thing for industry, but it is an open question whether transportation charges carefully gauged to the maximum weight which can be endured are not destructive in their ultimate result. If one takes many an article of manufacture and analyzes its cost he will often find that a large proportion of what he pays is for economically useless transportation of material together with intricate middlemen's charges which find their opportunity during the needless journeying. For a simple example, a man in Seattle buys a pair of trousers made in Philadelphia, of cloth woven in Massachusetts from wool raised in California, to say nothing of Texas cotton. Problem: of the $4.50 the Seattle man paid how much went to the actual makers of the cloth and the trousers, the sheep raiser and the cotton grower, and how much to the transportation companies and to the dozen or more unnecessary commissions extracted at various points?

Both transportation and commissions are to a certain extent necessary for industrial convenience, yet as time has gone on their importance has swelled until they are pretty nearly the whole thing. At a beautiful example of the other and more logical path, take the steel industry on the Great Lakes in which transportation and commissions have dropped to an irreducible minimum and the only freightage worth considering is that on the finished product which goes by the cheapest route, billed through to the consumer. It is to the development of minor transportation that one must look for industrial improvement. Just so long as it is necessary for goods to go along two long sides of the triangle instead of the short third side where there are no transportation facilities, so long will transportation and commissions pile their cent per cent upon the prices of the simplest things. The country needs more waterways and it needs, and needs very badly, better roads from place to place where industrial traffic ought to exist. Light railways and trolley lines must play their part also. At present the land is about in the state of a body provided with a heart and a full system of arteries and veins, but sadly lacking in capillaries. These must be furnished by roads and waterways, and improved means of utilizing both of them.

With a well-planned system of good roads the motor truck is capable of working a revolution in cheap carriage over moderate distances. It is not the man with the French touring car alone who needs good roads. The subject is one of national importance since it touches directly national industrial problems. It would be interesting to see what the lobby would do if it were really tried. Suppose Congress were to appropriate even $10,000,000 a year for the building and up-keep of first-class highways for the benefit of States that were willing and anxious to lend a hand, dollar for dollar, what a change even a few years would make in the practical facilities for getting commodities about the country. Public money is put to many worse uses than this, uses that benefit the community little or not at all. With a little wisdom in directing and gauging activity it would be quite possible to give a large and effective measure of practical relief to the unemployed during times like the present, at least to such of the unemployed as are not also unemployable. A network of thoroughly good roads would tend to scatter population, itself a very desirable thing, and would in this way quite make up the losses, if any, which existing railroads might suffer by the existence of available short cuts. The main gain locally would be not only greater commerce in all things but a better chance for local industries. Add to a good road system the systematic development of natural waterways and one would have a situation at last permitting something like a logical system of manufacture and distribution of manufactured things. Particularly it would be easier to escape the economic fault of sending a thousand miles materials which come back upon their tracks to the very next county, distant only in accessibility.

Auxiliary Steam Plant Capacity.

In many hydro-electric power transmissions the variations in the flow of the stream utilized are so great at different periods of the year that the construction of an auxiliary steam plant at some favorable point on the system is absolutely essential to the proper carrying of the load. The amount of reserve capacity installed exerts no little influence upon the financial operation of the system as a whole, and there is no problem in commercial power transmission deserving more careful investigation. Many hydro-electric systems have been created later than their auxiliary steam plants, and for this reason the presence or absence of economy in maintaining a given steam capacity is not always appreciated. Even in a long-established system it pays to check up every two or three years the cost of holding reserve capacity in a steam station, compared with the load requirements and possibility of further hydraulic development to obviate the need of retaining the original steam equipment.

The problem of reserve capacity is not one of great difficulty, but it is one which should not be neglected. The principal factors in the issue are the yearly load curve of the system, the power delivery possible at different months, the cost of generating steam power and hydraulic power, including the fixed charges, and the investment and yearly charges upon any feasible extension of the storage capacity above the forebay. In connection with the yearly load curve some allowance should, of course, be made for the probable increase of business in the system as indicated by the trend of both the connected and actual loads from year to year. The overload capacity of the machinery should also be considered in figuring the possible power delivery, particularly in carrying the system through the maximum load period of the year.

Electric power generated by hydraulic turbines is almost certain to be more economical at the point of delivery than the power generated in a steam plant unless the cost of hydraulic development far exceeds the original estimates, and unless the cost of maintenance and interruptions runs so high as to offset the advantages of no fuel expense. The assumption that electric power of hydraulic origin is always cheaper than steam power at the market place, regardless of the quality of engineering judgment displayed in the design of the hydro-electric installation, is certainly a very rash one to make without resorting to careful figures. The full story of power transmission expressed in terms of maintenance and fixed charges on lines of very high potential and in connection with elaborate hydraulic development has yet to be written. No outsider realizes the increasing difficulties of line maintenance at 40,000 volts and upward compared with 10,000 to 25,000-volt service. There is certainly room for more careful figuring of hydro-electric power costs in addition to plain operating expenses.

Primarily the question of auxiliary capacity is one of carrying the yearly load without interruption or inferior regulation of voltage at the consumers' lights and motors. Hydraulic plants are seldom so unfortunate as to be obliged to shut down entirely because of low water, though now and then high water creates exactly this trouble. As a rule, it is not necessary to install duplicate capacity in steam units, but, on the other hand, the installation of merely sufficient capacity to fill in the gap between the hydraulic capacity and the peak load is of doubtful wisdom in point of security against extreme conditions. Just where the safe middle course is must be determined by balancing the total cost of steam power, including fixed charges, stand-by expenses, operating expenses and perhaps extra depreciation of idle equipment, against the total cost of hydro-electric power, both on the basis of present and future development, including in some cases forfeit penalties for the failure of the supply, or what is often substantially the same thing, lost revenue. Transmission costs must be included if the steam and hydro-electric plants are not at the same distance from the power market. In the great majority of cases it is unthinkable to plan insufficient capacity to carry the load under extreme conditions, but in facing an unprecedented shortage of water, occurring perhaps once in 15 or 20 years, some risk can be taken with judgment. Long series of flowage and river-stage records are invaluable helps in the analysis of all hydro-electric power problems.

Specifications for Concrete Hollow Blocks.

Concrete hollow blocks like a number of other concrete and reinforced concrete products have come to stay, and have already found a wide and rapidly widening application in building construction and in some other lines of work. They constitute a useful and attractive building material in consequence of the ease with which they can be made of any shape, and because they may be conveniently and economically laid. Their utilization constitutes, so far as modes of manufacture and procedure in building are concerned, practically an extension of the use of bricks. Further than this, they possess an advantage over the latter in ease of manufacture and especially in the ease with which void spaces may be formed in the concrete, thus making, what is frequently much desired, an air space in the wall. At the same time they have one other characteristic, porosity, in which they are unfortunately much too like brick. Any process of manufacture or simple, economic treatment which will eliminate the porosity of the hollow concrete block will add much to its value. Again, inasmuch as the hollow blocks are bound to be used where more or less heavy loads will come upon them, it is of the utmost importance to be assured that they have the requisite carrying capacity, not only at the time of laying them, but also at a subsequent period when they receive their greatest loadings. While the operations of hollow concrete block making constitute practically shop work and they may consequently be controlled with corresponding ease and accuracy, it is imperative that these concrete shop operations, so to speak, should be subject to just as stringent specifications as those which belong to the fabrication of steel structural members, also a shop operation. This is all the more necessary from the fact that the manufacture of concrete hollow blocks is essentially a new industry.

For these reasons it is a matter of some consequence to observe "The Standard Rules and Regulations Governing Concrete Hollow Block," recently adopted by the National Association of Cement Users and printed in this journal on March 7. It is full time that suitable specifications for this special field of construction should be carefully considered, not only by the manufacturers of hollow concrete blocks but by engineers and users of this class of cement products. There are a number of featurs of this work which should be carefully controlled by specifications, such as those conditions which reduce the porosity of the concrete, thus attaining as nearly a waterproof material as practicable. While it is impossible to secure in this manner an actually nonabsorbent artificial stone, the porosity can certainly be much reduced by suitably selecting and grading the aggregate so as to reduce the voids to a minimum and then using a fine ground cement to an amount a little more than sufficient to fill those voids. It may be necessary for some purposes to submit the blocks before the setting of the cement to a suitable intensity of pressure in order to secure the desired density of the finished product.

It is also a matter of much importance to proportion the voids in the blocks so as to keep the total percentage of open spaces in the finished wall within desirable limits. The maximum percentages of these hollow spaces are fixed in the Cement Users' specifications at different amounts for different heights of walls, which is probably judicious as a general plan. This feature of a hollow block wall, however, is of much importance to the finished construction and it should receive the most careful consideration in view of all the conditions which are affected by it. Manifestly the thickness of the sides of the blocks must be adapted to the amount of loading at the points where loads are applied, as is indicated in the specifications under consideration.

The different kinds of tests to be prescribed for these blocks is another matter requiring the most careful study in view of the peculiar duties which the blocks must perform. The method of prescribing certain ultimate bearing values for the entire area of the block section without regard to the hollow spaces may have to be changed. The concrete of the walls of the blocks must have a satisfactory resistance per square inch of actual cross section, otherwise the actual compressive resistance of the concrete may be completely hidden by the sectional area of void space. Probably no test will be prescribed eventually except such as show the actual character of the material itself. The absorption and transverse tests are obviously essential and they should always be carefully made. The absorption limit of 15 per cent. as an average and 22 per cent. as a maximum may be well enough for some cases but quite unsatisfactory for others.

The specifications serve an excellent purpose as indicating what is much needed, and those engineers who are engaged in hollow concrete block work should give this matter of suitable specifications careful study and prescribe the requisite features of their work in such way as to attain the best results with greatest attainable economy and the least difficulty.

The Quebec Bridge.

The Royal Commission of Enquiry appointed by the Governor General of Canada on Aug. 31, 1907, to investigate the causes of failure of the Quebec bridge has made its report, under date of Feb. 20, which is printed in full in this issue of The Engineering Record. The Commission comprised three eminent Canadian engineers, who were equipped with full authority not only to examine and investigate all the physical conditions attending the failure of the structure, but also to summon witnesses and secure such evidence as in their judgment might seem desirable. A perusal of the report and its appendices discloses the fact that the commissioners have made active and thorough use of the authority with which they were clothed and that they have also availed themselves of the professional advice and aid of some of the most prominent bridge experts in this country in reaching their conclusions. In fact, it is difficult to discover in what way the Commission could have been more assiduous in the various directions in which it has pushed its enquiry.

The circumstances under which this bridge was designed and under which its construction was carried on to the date of the disaster are rather unusual, although by no means heretofore unknown in American practice. The Quebec Bridge & Railway Co. was organized with a chief engineer of experience in some lines of engineering work, but without extended experience in bridge work, in spite of the fact that the principal object of the corporation was the construction of the 1800-ft. cantilever bridge across the St. Lawrence River. It was manifestly impracticable, therefore, for the engineering organization of the Quebec Bridge & Railway Co. to prepare plans and specifications for the structure which it was about to build. It would appear also that possibly in consequence of the lack of a strong financial foundation at first, it followed the procedure of inviting bids for the contemplated work on plans and specifications to be submitted by the bidders themselves, the latter being guided only by general instructions. This procedure created at once a position likely to be productive of much difficulty, which would require the exercise of unusual professional ability and tact on the part of someone in avoiding the chances for controversies.

In the early stages of the work, in order that the company might secure the services of a prominent bridge engineer of experience and reputation, Mr. Theodore Cooper was appointed consulting engineer and made supreme in authority as to all parts of the design and construction of the bridge, from the mill inspection to the completed structure. His authority was absolute as to all questions whether in the mill, in the shop or in erection, and was ultimately secured by governmental order. This action secured the official approval for the Quebec Bridge & Railway Co. of a prominent specialist, so that whatever may have been proposed or suggested in the original plans of the contractor, the company might feel assured of a suitable design for its purpose and rest assured as to the safety and sufficiency of the great steel structure designed ultimately to carry the railway traffic of one of the Canadian transcontinental trunk lines as well as such trolley or other street traffic as might seek the accommodation of the bridge. Some emphasis is laid upon this particular part of the history of the enterprise for the reason that many engineers will undoubtedly contend that had the plans and specifications first been prepared under the supervision of an experienced bridge engineer the limitations of the procedures first taken would have been avoided, thus escaping the final catastrophe. Be that as it may, however, it appears, as stated in the report, that the defective design originated in the office of the Phœnix Bridge Co., but was approved and accepted officially as his own by the consulting engineer.

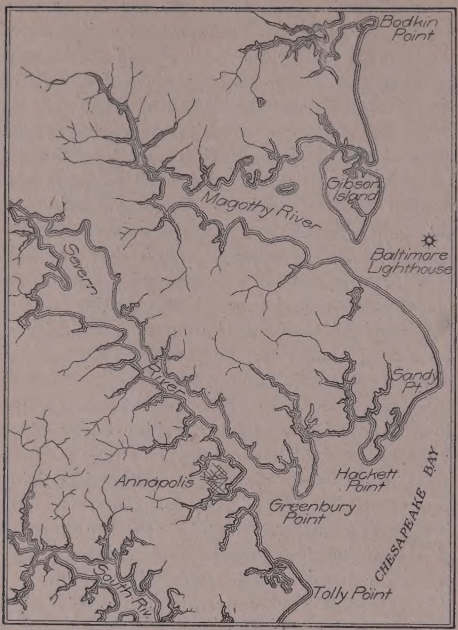
The Commission states conclusively what has in reality been known for some time by those who have followed the matter, that the collapse was due to the failure of the lower-chord compression members of the southerly anchor arm of the bridge, probably in the second and third panels from the main pier between the anchor and cantilever arms, as has been shown in the columns of this journal. At least one of these lower-chord segments showed serious bends or buckling of the webs a few days prior to the collapse. It is furthermore shown that the defective design of those members, observed and set forth by the Commission, finds expression in lattice bars far too weak for their duty and in web flange angles far lighter than they should have been. In other words, the section of these heavy compression chord members, each consisting of four webs, was badly "balanced." As these chords were 54 in. deep, their proper design demanded heavy lattice bars and flanges wide enough to have given them much initial stiffness in themselves; neither of these conditions was fulfilled. The initial failure of the structure took place at a stress of about 18,000 lb. per square inch in these lower chord members. It is highly significant that when an exact model of one-third full size of these chord members was made and tested at the shops of the Phœnix Bridge Co., in the presence of the Commission last November, it also failed at practically the same compressive stress per square inch, and by the failure of the lattice rivets without any sign of buckling or other yielding whatever of the webs of the model member. This result in itself is conclusive evidence of the cause of failure.

The Commission criticized sharply a grave error in assuming the dead load for the calculations at too low a value and not afterwards revising this assumption. Obviously in such a structure as this, the dead load, being the chief burden of the structure, should not be underestimated; at the same time, an underestimate of even 4 or 5 per cent. would carry with it no essential hazard. Unfortunately, however, a graver error was the extraordinarily high working stresses permitted in the design. Compressive stresses running possibly from 24,000 to 26,000 lb. per square inch in compression members, due to the loading of the railway tracks only, are too high for safe and judicious construction. It is altogether probable, if not certain, that however carefully carbon steel compression members may be designed their ultimate carrying capacity will fall considerably short of double these working values, and in some cases such working stresses might easily be dangerously near the elastic limit of the members. It is true that some extraordinarily heavy structures have been built with working compressive stresses approaching 24,000 lb. per square inch, but only where there is a multiplicity of trolley or elevated railway tracks, roadways and sidewalks the concurrent loading of all of which is essentially impossible, the working intensity in question being a maximum for the greatest supposable congested load.

The Commission lays much stress upon the lack of "professional knowledge of the present day concerning the action of steel columns under load ———." This is largely true and the fact has received the editorial comment of this journal, but at the same time too much should not be made of that general fact. The real lack of knowledge is in connection with the design of latticing. Engineers know little or nothing as to any proper theory of that design. Such meagre experimental tests as have been made with steel columns have not been conducted with a view to throwing any light upon this matter, and there is no possible analytic theory, in spite of much that has been written on this subject on assumed bases. Given an adequate method of designing lattice bars or other spacing members, the carrying capacity of even steel columns can be computed with a fair degree of approximation. In such great compression members as those which failed in the anchor-arm chords of the Quebec Bridge cover plates should be used on their tops, leaving the lower flanges to be held by properly designed latticing. There is at least one fruitful issue to arise from this appalling catastrophe and that is the thorough and comprehensive experimental study of full-size steel columns which is bound to follow.

The report as a whole is fair and judicial in its tone. It recognizes the grave difficulty under which the engineers labored in making the design and in carrying out the erection. It compliments the contractor upon the skill and efficiency of its organization in the office and shop and in carrying out the erection, and the tortured and twisted condition of much of the wrecked material at the bridge site is a superb tribute to its quality, confirmed also by the Commission's report. The Commission is unquestionably right in stating that the fall of the bridge could not have been prevented by any action that might have been taken after Aug. 27, 1907. The question of responsibility for the disaster as due to defects of design, they do not attempt to settle; they simply state, what is obviously the fact, that the design was officially approved by the Consulting Engineer whose supreme authority was fixed by an "Order-in-Council."

The Septic Tank Litigation in this country has evidently not been terminated as yet, for on Monday of this week the representatives of many cities and several State boards met at Harrisburg and organized a permanent association to oppose the collection of any royalties based on the decision of Judge Ray, printed in this journal on Jan. 25. The general affairs of the association have been placed in the hands of an executive and finance committee made up as follows: Chairman, F. Herbert Snow, chief engineer Pennsylvania State Board of Health; secretary, R. Winthrop Pratt, chief engineer of the Ohio State Board of Health; treasurer, G. A. Johnson, principal assistant engineer with Hering & Fuller, New York; Wade Ellis, attorney general of Ohio; Robert A. Cairns, city engineer of Waterbury; T. Chalkley Hatton, consulting engineer, Wilmington; G. Everett Hill, consulting engineer, New York. The official announcement regarding the association's purpose has not been given out yet, but it is understood that the organization will defend vigorously any attempt to collect royalties for the use of the septic process of sewage treatment and will endeavor to secure the reversal of the recent decision in favor of the Cameron septic patent. It is evident, therefore, that this patent is likely to be the cause of a legal battle of the most important character, not only to engineers engaged in sewerage work, but also to all inventors of processes, since the general defense in this case is understood to be that the septic process is one of those natural changes that occur whenever the conditions are favorable, and that such conditions may be natural or artificial without affecting the results of septic action.



The Site of the Lighthouse.

The Construction of the Base of Baltimore Light, in Chesapeake Bay.

DESCRIPTION OF A UNIQUE SALVAGE UNDERTAKING FOR A LARGE PNEUMATIC CAISSON.

By H. Prime Kieffer, Berlin, Germany.

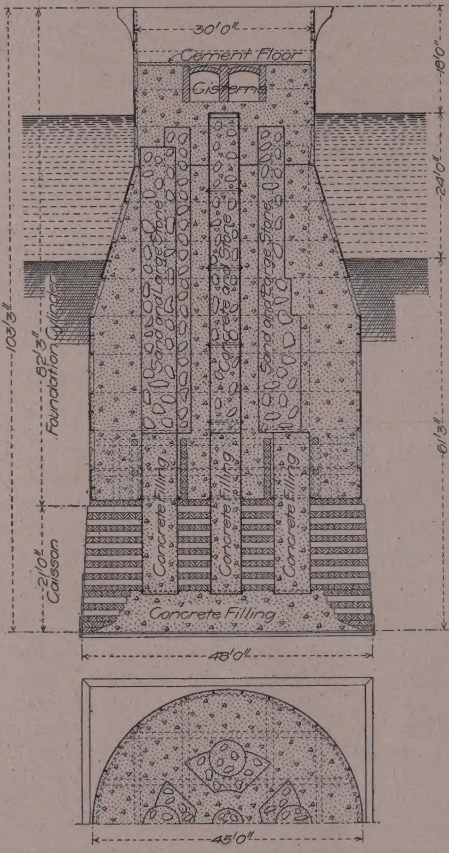
The completion of the base for the Baltimore Light in Chesapeake Bay, two miles off the mouth of Magothy River, in the main ship channel to Baltimore, closes one of the most interesting undertakings in recent years in connection with difficult foundation construction. The work was started in 1904, and after extraordinary vicissitudes, was completed by the United States Fidelity & Guaranty Company, of Baltimore, under the direction of Mr. Chas. F. Wood, its chief engineer for a number of years, who has recently been elected vice-president and general manager of the Breakwater Construction & Engineering Company, of New York and Cleveland.

The lower part of the base consists of a square wooden caisson measuring 48 ft. on a side at the bottom, 46 ft. on top and 21 ft. high, having the usual working chamber and air and dredging shafts. This caisson carries a cast iron outer cylinder, 45 ft. in diameter for the lower five courses, then rising in a conical shape for four courses, and then rising for three courses with a uniform diameter of 30 ft. to a trumpet-shaped top. The total height of the cylinder is 82 ft. 3 in., and the total height of the whole foundation pier is 103 ft. 3 in.

Work on the caisson was started at Lazarette Point, Baltimore Harbor, in the spring of 1904 by the original contractors, Flaherty & Lande. On account of various delays the caisson was not ready for launching until the middle of summer. Owing to some miscalculations difficulty was experienced during the launching and the caisson ran off the ways and grounded in the mud. After a long delay, a dredge was brought into service and the mud dredged away from the front of the caisson. The Baltimore ice boat and a number of powerful tugs were then attached to it and succeeded in getting it afloat. It was then moored alongside the United States Engineer wharf and two rings of flanged cast iron plates, each ring 45 ft. in diameter and 6 ft. 3 in. high, were bolted to it. The contractors then towed the caisson to the site, which was reached on Sept. 19, 1904.

The structure had to be sunk through 55 ft. of mud, a 4-ft. stratum of coarse sand and finally into about 2 ft. of fine sand, in which it was expected to come to rest. The different methods of sinking which the contratcor was permitted to use, were described in the specifications as follows:

"1. The design shows four outer shafts, each 6 ft. in diameter, placed 11 ft. from the center, and one shaft 5 ft. in diameter, in the vertical axis of the structure. The contractor may extend these four outer shafts, open on both ends, below the line of the cutting edge, to be filled with water to the high-water mark and then used as dredging shafts only, until the whole structure rests on the bottom datum line. The center shaft is to be used at first as a dredging shaft; later on when provided with an air lock for application of pneumatic pressure, as an air-shaft. With the filling of the working chamber with concrete, the closing of the four outer shafts should be connected in the same way and be continued to a height of 12 ft. above the top of the 21st caisson course; the remaining part should be filled with sand and stone.



Sections of the Foundation.

"2. The contractor may carry all the shafts only to the roof line of the working chamber, and use them in the first part of the operation of sinking for dredging shafts. Later on, when dredging can be discontinued and compressed air advantageously used for the final sinking of the structure, these four outer shafts are to be fitted with air locks. The 4-ft. center shaft shall always, except as noted under 1, be used as an air-shaft, and for admitting the workmen and materials.

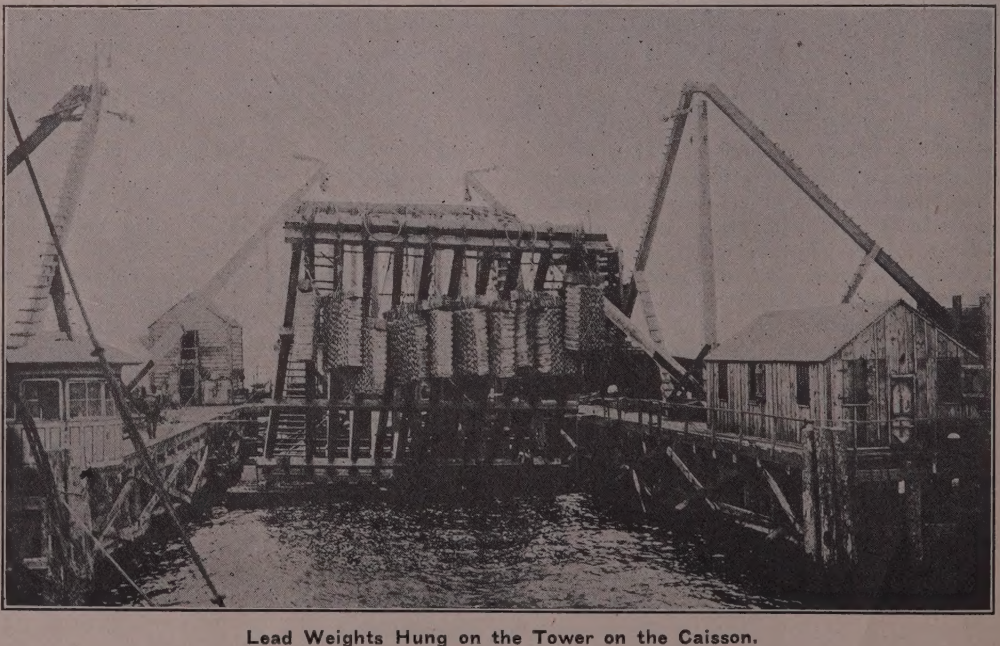
"3. The contractor may make use of two of the 6-ft. shafts for dredging, and apply the air pressure on the two other 6-ft. shafts. The center shaft to remain as stated in No. 2.

"4. The contractor may decide to omit the use of one, two or all of the four outer shafts and rely for sinking only on the central air-shaft as the pneumatic process may be used. With the approval of the lighthouse engineer, the diameter of this center shaft may be enlarged."

The specifications further stated that after the caisson had been moored in place it was to be lowered at high tide by gradually extending the cylinders and shafts in height and filling in with concrete. The specifications permitted the loading of the caisson as soon as it touched bottom, and stated that the character of the upper stratum was such that little resistance to sinking by weight alone would be offered. Later on, the process of dredging or pumping was permissible until the depth was reached where it would be advantageous to introduce compressed air.

When the caisson arrived on the site on Sept. 19, 1904, the contractors immediately began to fill the rings with concrete. Two more rings were added, making the cast-iron cylinder 25 ft. high. The water at the site of the lighthouse was 24 ft. deep and the caisson with the two rings on top drew about 23 ft., and was floating with the cutting edge just above the mud. This mud was so soft that a pile stood on its end sank 15 ft. into it of its own weight. It was the intention of the contractors to load the rings with concrete until the weight should cause the caisson to sink through the soft mud to the harder stratum below, after which it was intended to put on the air and sink the caisson by the ordinary pneumatic process. To expedite the work it was proposed to dredge the mud through the dredging shaft with an orange-peel bucket.

For the purpose of carrying on the work the contractors provided three barges about 200 ft. long, one of which was an old bark with all three masts in place and the others were old ferry boats. These barges provided quarters for a crew



Lead Weights Hung on the Tower on the Caisson.

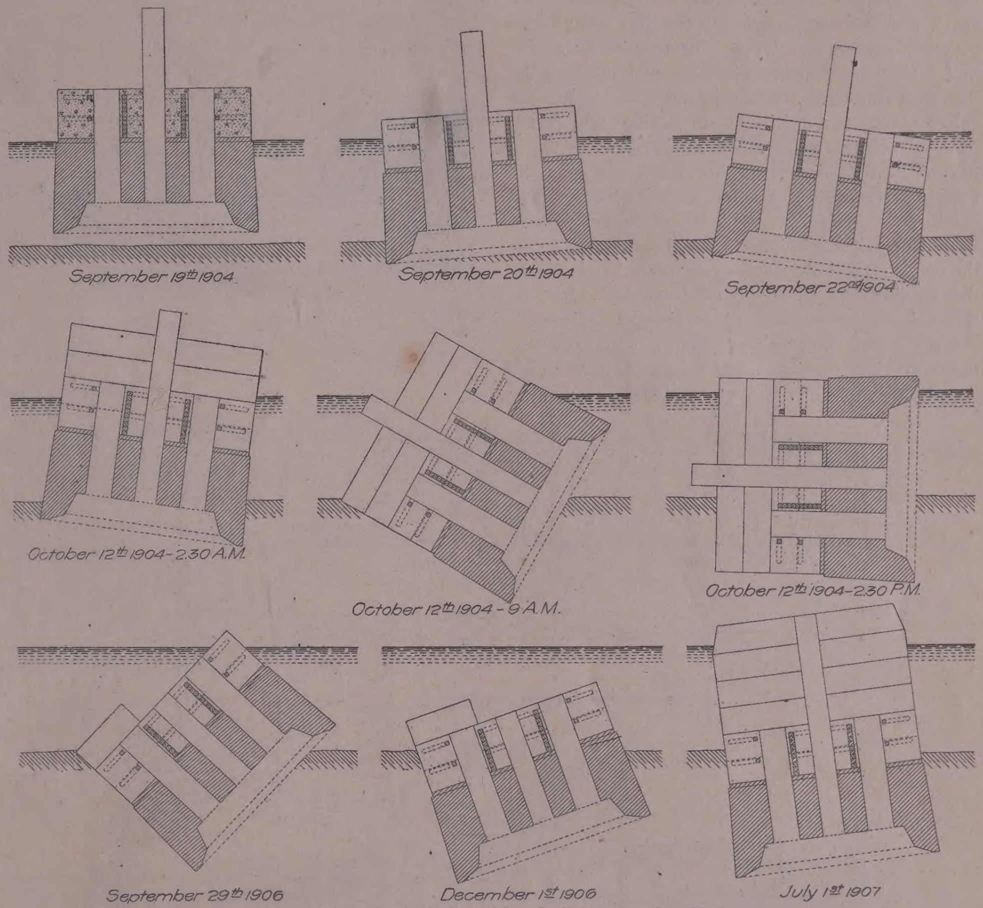
of about 150 men and one of them was fitted with three boilers, two air compressors and other appliances necessary for carrying on the work.

Owing to bad workmanship the deck of the caisson leaked considerably and as the specifications required the concrete to be laid in the dry, the necessity of stopping the leakage caused further delay. Finally concreting was started and about 1 ft. was placed uniformly over the whole deck. The space inside the two lower rings was divided into three parts by two parallel watertight bulkheads 12 ft. high and running north and south, after the caisson was anchored in position and the concrete was placed alternately in each of the outside pockets. When the concrete in the east pocket was 4 ft. 9 in. above the deck, that in the west pocket was 2 ft. or more below it, and the whole structure took a list to the east. More concrete was then rapidly thrown into the west pocket until it reached a height of about 13 ft., when the top of the structure began to move to the west. This point was reached on the morning of Oct. 12, when a gale came on from the northeast, in which direction the site is exposed to the whole sweep of Chesapeake Bay. As a result, before night the caisson lay with one side 46 ft. below the surface of the bay and the other just a wash, while the contractors' boats were blown ashore and lay among the breakers 2 miles to leeward. The next day the contractors made an assignment. The movements and positions of the caissons at various dates are shown in one of the figures.

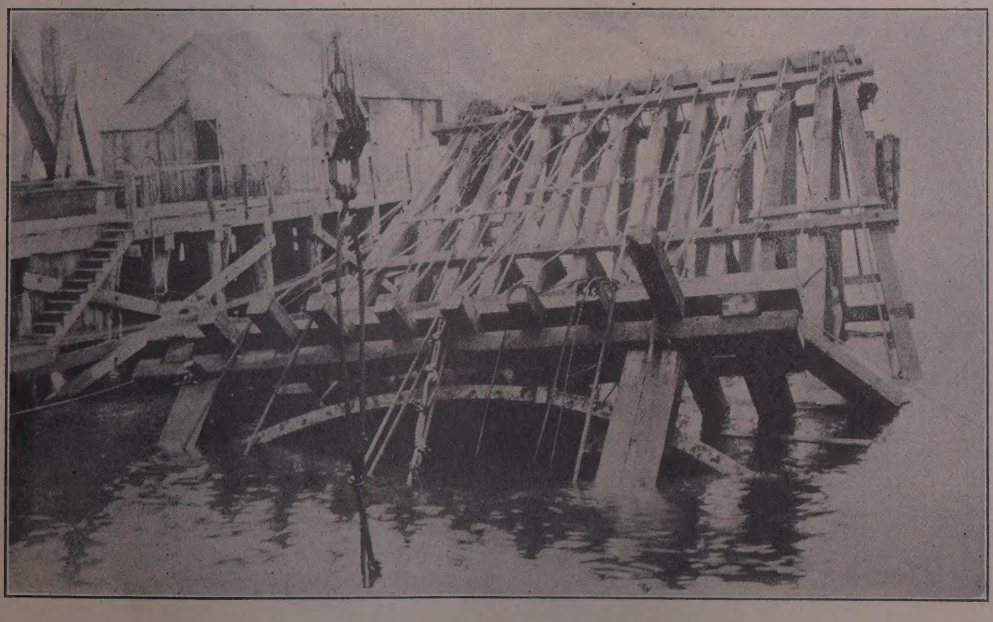
The contractors claimed to have spent about $70,000 on the work up to this time, a considerable proportion of which was for plant and equipment. The loss of the caisson is considered to have been caused by bad judgment and lack of the ordinary precautions in such work. If, instead of mooring the caisson with a few anchors and attaching to it three large and clumsy barges, all of which, including the caisson, were tossed about by the waves, a half dozen dolphins of heavy piles had been driven, and the caisson and barges had been properly moored to these, it is considered probable that the whole equipment would have ridden out the gale of Oct. 12, although the overloading of one side of a structure having such a high center of gravity was a fatal error.

The winter and spring of 1905 were wasted in discussions between the receiver and the creditors of the contracting company over ways and means to right the caisson and complete the work. The Light-House Board finally declared the contract in default in June, 1905, and called on the United States Fidelity & Guaranty Company, surety on the contractors' bond, to complete the work. In August the surety company made a sub-contract against Mr. Wood's advice with a New York contractor. He worked for the rest of the season and took off some of the segments of the cast iron ring for the purpose of removing the concrete that had been deposited on the deck by the original contractors. Nothing of real value was accomplished and in the spring of 1906 the subcontractor was ordered by the government to stop work. The task was then undertaken by the U. S. Fidelity & Guaranty Company under the plans and direction of Mr. Wood.

After a careful study of the problem, it was decided that the best way to right the overturned structure was to construct a tower derrick on the caisson, and suspend on it enough lead to shift the center of gravity to a point near the toe or cutting edge of the caisson, and then apply sufficient force by hoisting engines and derricks to revolve the structure through a quarter-turn.



Successive Positions of the Caisson at the Site.



Position of Tower with Caisson Partly Righted.

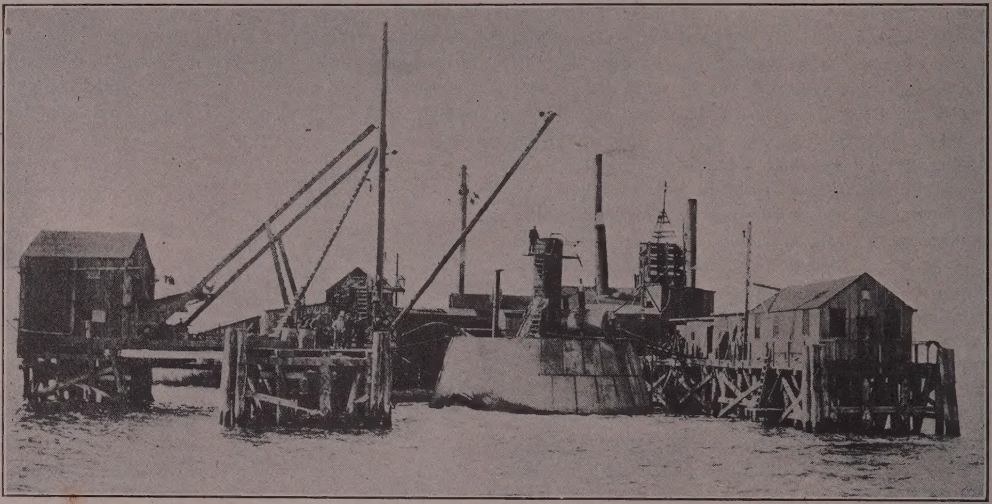
In order to insure stable working conditions, and eliminate the chance of disaster at a critical moment, a wharf was constructed around three sides of the caisson, substantially as shown in one of the illustrations, 309 piles 75 to 80 ft. long being used on this structure. On this wharf were installed the boilers, engines, compressors, two 25-ton derricks and other plant and the houses for the protection of the machinery and men. The derricks had 20 x 20-in. masts 40 ft. high and 16 x 18-in booms 65 ft. long, and were fitted with seven-part fall lines and nine-part boom lines. To secure fresh water for the boilers and other purposes, a 6-in. well was driven into the bottom of the bay about 184 ft. below high water, at which depth a stream was tapped under a head of about six feet, which overflowed the pipe into the bay, like a fountain. This well furnished practically all the water used on the work, and at the time of greatest activity supplied nearly 30,000 gal. per day. The water being somewhat impregnated with sulphate of iron, during the latter stages of the work, a home-made iron pipe condenser was used to supply water for drinking and cooking purposes. The value of the well can be gathered from an experience in bringing down one scow load of water, which cost $2.50 at Baltimore, but which for towing and other charges represented a cost of $69, when delivered on the work, and was all used in one day.

The first operation on the caisson was to replace by divers some of the plates removed by the sub-contractor above referred to. The second and third rings, which had been partially taken off being re-completed, the tower was built on the caisson in the manner illustrated. Seven lengths of 2-in. plow steel cable was drawn under and around the rings as shown, and both ends of each carried over the top of the tower and to the end of the boom. A mass of pig lead was bunched into ten weights of 12 tons each and suspended at the end of the boom. Three spuds made up of four 24-in. 80-lb. I-beams 32 ft. long were slipped through three of the dredging shafts, and by means of saddles given a bearing on the upper side at the deck of the caisson, and on the lower side at the roof of the working chamber. One of the 12-ton weights was hung on the center spud, and one of the large derricks above referred to was attached to each of the side spuds. Four-part lines rove through double blocks were carried to the front, rear, and side from the top of the tower on each side and the leads taken to the six drums of three double-drum engines. A trench was pumped in the mud all around the caisson down to the lower edge, and the mud was partially removed from in front of the caisson.

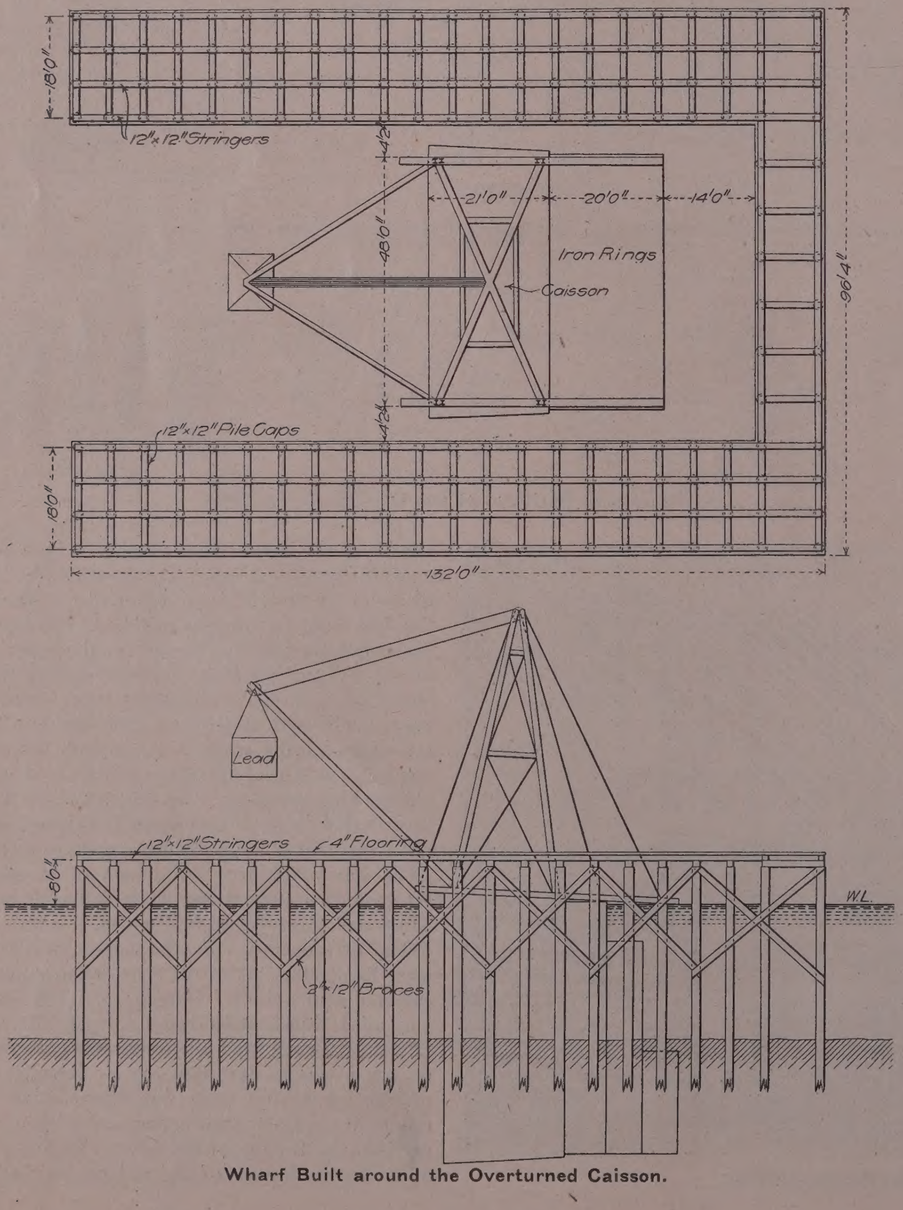
In addition to the force applied directly to the caisson itself through the spuds above described, extra precautions to prevent the iron rings and concrete pulling away from the woodwork at the lower side, by reason of an unequal pull on the iron and wood, were taken by tying the rings and caisson together with 1¼-in. cable and turnbuckles. Hooks were made to go over the upper flanges of the third course of plates and over the cutting edge of the caisson. Forty of each were used, and the pairs fixed together with cable, drawn up with turnbuckles, as above, so as to tie the iron and timber into one mass, and insure the turning the structure as a whole. Most of these ties were placed and made up by divers.

Nearly two months were lost waiting for two large derricks, which were bought for May delivery, but finally, on Sept. 29, 1906, everything was declared to be ready and the first effort to move the caisson was set for the next day.

In estimating the weight, displacement, leverages, and other factors, it was calculated that 100 tons of lead, acting with a lever arm of 58 ft. would bring the mass in equilibrium on the axis of the center of gravity of the wooden caisson. The additional 20 tons was added to insure that the neutral axis should be between the center of gravity, about 7 ft. from the deck, as planned by the United States Lighthouse engineers, and the cutting edge of the caisson.



The Caisson after It Was Righted.



Wharf Built around the Overturned Caisson.

On Friday, Sept. 29, when 95 tons of lead had been hung in place, that weight aided by about 3 tons weight of boom and 2 tons of cable caused the structure to move forward about 1/16 in. per hour.

Late that evening the balance of the lead was hung. A test was made with the hoisting engine, and the mass moved forward about 3 ft. Then to prevent the forward movement, which kept on at the rate of more than 1 in. per hour, the lines to the rear from the top of the tower were tightened and everything held in place, until the arrival of the invited guests at noon the next day.

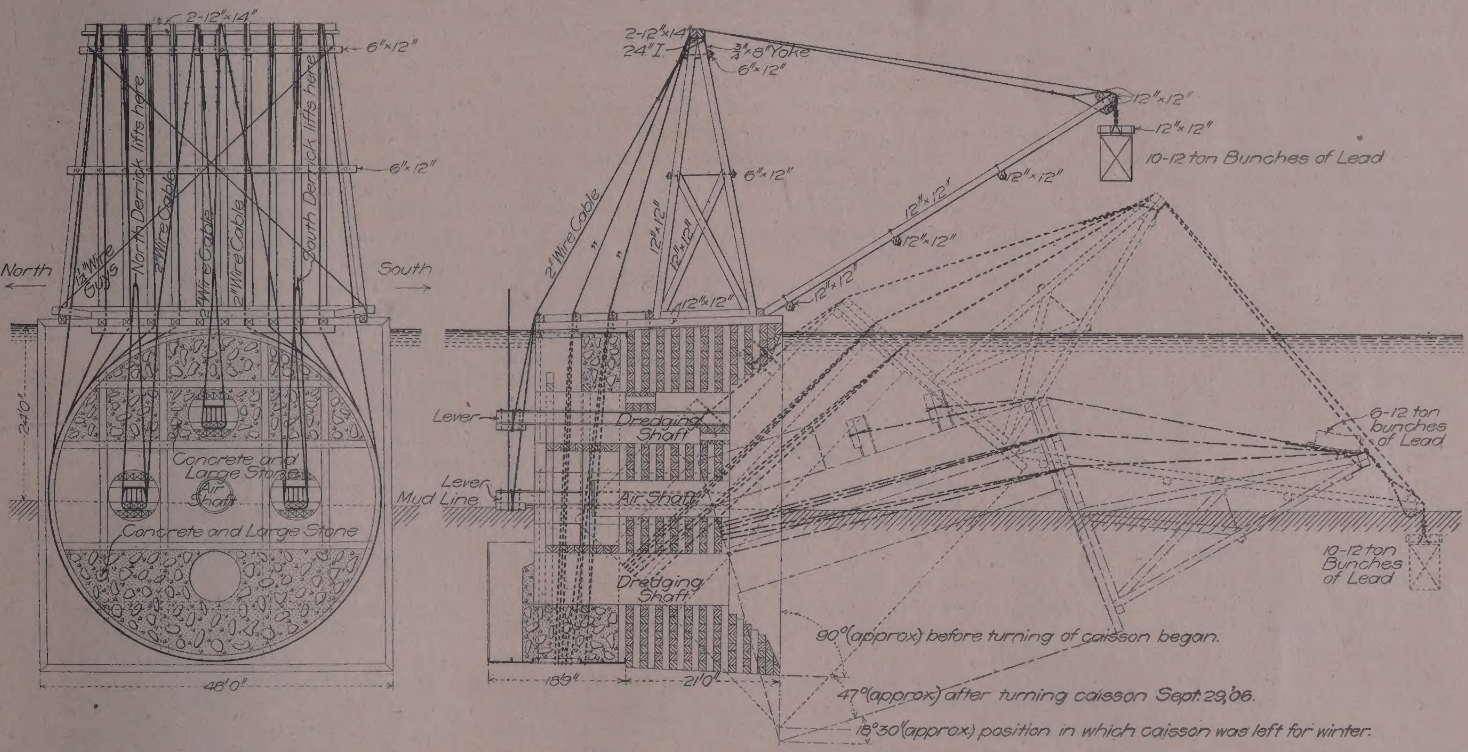
On Saturday, Sept. 30, the president of the company, the lighthouse officials and guests arrived. At 1 p. m. the stops were cast off the lines, the word given, and the structure turned through about 47 deg. in about as many seconds. Everything worked out just as planned and before night the divers were down hooking on to the lead weights, which had brought up on hard bottom. During the next few days, one by one, the 12-ton bunches were lifted, and laid on top of the tower. The cables to which the lead was attached were pulled aside; the boom released and floated out of the way, large centrifugal pumps with jets attached to the suction pipes were started, and the mud under the high side removed allowing the caisson to settle slowly into the bottom.

Cold weather interrupted the work about Dec. 1. All the machinery was removed from the wharf because of the possibility that the ice, which in this particular part of the bay is very troublesome, might carry it away. The wharf stood, however, and except for the breaking off of a few piles, everything was found intact when work was resumed in the spring of 1907.

Early in April, the machinery which had been stored on one of the barges, two of which had been sunk on the flats in the Magothy River, was again installed on the wharf. One of the barges was kept afloat and became one of the most useful helps on the work. The old hulk was never laid off the job, being moved round and round the wharf to find a lee when storms blew, all of which it outrode gallantly, and there was not a point on the wharf where her 70-ft. boom could not be brought to bear to lift and perform whatever work the fixed derricks were not able to reach. It would have been practically impossible to have carried through the work without an appliance of such kind as this boat provided. The two large derricks previously mentioned were replaced by a tower and the two 12 x 12-in. booms with three and four-part lines for lighter and more rapid work.

The tower was removed from the side of the caisson; the 2-in. cables were withdrawn from around the rings; the spuds were taken out of the dredging shafts; pumping was resumed, and the plates of the fourth, fifth, sixth, and seventh courses of iron rings were put in place, most of them under water with the aid of divers. This brought the structure above water. A 1¼-yd. cube concrete mixer was installed, and ten 20-in. 65-lb. 60-ft. I-beams were thrown across from the two sides of the dock, and floored to secure additional space. A cement house and other structures were built. Temporary wooden doors were fitted at the bottom of each of the four dredging shafts and concrete to the depth of about 6 ft. was deposited in each by means of a bottom dump bucket. While this concrete was settling additional sections of the air shaft were added to bring it above water, and preparations were made to pump out the cylinder.

In turning the structure, the cutting edge of the caisson, which at the start was about 46 ft. below the surface, sank about 11 ft., the movement being forward and down at the same time, so that the deck of the caisson was about 36 ft. below the surface of the bay, when the time came to empty the cylinder of water. The displacement of the cylinder was about 50 tons per foot of depth, and weight to the extent of about 1800 tons had to be provided to prevent the structure from jumping out of the water like a big cork. This was provided by rubble boulders weighing from ½ to 4 tons each, which were lowered into place by derricks and placed by a diver. Several scowloads of sand were also thrown into the cylinder. Old sails were wrapped around the outside of the cylinder, wound with many turns of hemp line, hove taut with an engine, and the pumps were started to clear it of water.



Tower Built on the Overturned Caisson and Its Successive Positions during the Work.

At this point came one of the most troublesome and expensive difficulties of the whole operation. It had not been considered that emptying the cylinder presented a serious problem, but on trial with a 10 x 8-in. Lawrence centrifugal pump with an 8 x 8-in. engine, it was found that while the water could be lowered about 3 ft. in about 11 minutes, it returned at the rate of 300 cu. ft. per minute, and in 15 to 16 minutes from the time the pump stopped the water level inside and out was the same. Experiment after experiment was tried but it was like trying to pump out the bay.

Finally a new canvas, 37 x 150 ft., made of No. 4 duck was secured, cut to fit the batter of the sixth course, and well roped around the edge. This was drawn around the cylinder and tightened up with an engine. Strips of 1 x 6-in. wood were put along the vertical joint inside and outside, and the two strips nailed together every 6 in. by a diver. This reduced the leakage more than half, but the flow was too strong to permit laying concrete. Then about 4,000 cu. yd. of mud were brought from one of the dredges working in Baltimore harbor and dumped in the slip between the points of the wharf, after which a ¾-yd. clam-shell bucket was used to bank the mud around the cylinder. By this means the leakage was reduced to insignificant proportions, and thereafter was handled conveniently by a No. 3 Emerson pump, running an occasional stroke. Practically all this trouble, delay and expense were caused by the removal of the plates, which was the only thing done by the sub-contractor who attempted the job after the failure of the original contractor.

Each of the 45-ft. diameter rings were made up of thirty cast iron plates about 5 ft. x 6 ft. 3-in. x 2-in. thick. These plates had 8-in. flanges all around and were bolted together by 2-in. bolts.

The specifications required that the joints between the plates should be made above water, with oakum and red lead. The first four courses were made up by the original contractor in that manner. The sub-contractor referred to removed the fourth course entirely and a part of each the second and third courses. All of these plates had to be replaced under water by a diver. It was practically impossible to make the joints between them tight, and when these open joints received the pressure from a 30-ft. head the water came through in a stream. Very little trouble was experienced with the two upper courses, the joints of which would have been the only ones to have been made under water, but for the removal of the other plates. The pressure against them was light and it was very easy to pump the water down below them, and with pine wedges stop such small leakages as showed, but the lower joints exposed to heavy pressure and buried under hundreds of tons of stone, presented a totally different problem. The sand, which was to have been used as a form to put in a ring of concrete about half way down to act as a weight to hold down the cylinder while the stone was removed from below and the pockets on the deck concrete, flowed like quicksand with the strong current and every bit had to be pumped or shoveled out before the difficulty was overcome. Weeks of valuable time and many thousands of dollars were wasted because of this mistake.

After this difficulty was surmounted, the cylinder was quickly filled with concrete up to the middle of the sixth course, the large stone being moved from side to side until it was placed on the concrete. At no time was the weight allowed to drop below the safe load required to hold down the empty shell.

In making the calculations for stability, it was assumed that the wooden caisson, which had been nearly three years in the bay, had become so waterlogged as to neutralize its buoyancy, and nothing was observed during the progress of the work to change this conclusion.

The Emerson pump was continued in service for nearly three weeks, almost without a stop and with practically no attention, until the concrete was brought above the surface of the bay, a sump being left all the way around the deck of the caisson. Iron pipe channels were left at various points leading to this sump. After the pump was removed, the sump was closed except for a 2-in. pipe connection to which a grouting machine was attached, and the sump and all of its channels pumped full of grout under an air pressure of 140 lb. The cubic contents of the sump and its connections were very carefully calculated, and a sufficient amount of grout was forced in to entirely fill the space. Thereafter the surface of the concrete was never allowed to get below water level. During the period when concreting was going on, the air compressor plant was thoroughly gone over, an electric light plant was installed and men and material locks were secured. A hospital lock was fitted up and a physician experienced in the care of men working under compressed air placed in charge as medical director.

The class of labor was rapidly changed. Sand hogs were brought from New York under experienced foremen. The locks were placed, air turned on and the sinking commenced and continued without interruption until the end.

Some of the clay stratum on which the caisson rested when air was turned on, was taken out with shovels and a bucket, but most of the material was blown through a 5-in. iron pipe carried up in the air shaft and turned overboard. At its end it was fitted with a short length of 4-in. suction hose, and a 4-in. plug cock served to close it when necessary. The material was washed to a sump by one or more jets from a 2½-in. fire hose and nozzle supplied with water by a pump on the dock.

The men worked in two shifts, varying from four hours each at the beginning to one hour each at the end. The air pressure varied from 25 to 40 lb.

One of the serious troubles the men had to contend with at the start of the air work was sinking through an old oyster bed or bar at a depth of about 60 ft., which evidently had once been the bottom of the bay. The oyster shells, which were very numerous, clogged the blow pipes, cut through rubber boots, gloves and skin, making the progress slow, difficult and painful.

No man was allowed to go into the compressed air until he had been examined and passed by the doctor, and only two slight cases of the "bends" developed, both of which were relieved in a few minutes.

The material lock was fitted with large connections and valves so that materials could be locked in and out rapidly, but the man lock, which was on the side and entirely separate from the other one, was fitted only with a ¾-in. valve, and so rapid ingress and egress was impossible. It is common practice on similar work to use as large a valve as 2 in. This condition caused considerable complaint on the part of the men at first, but they were soon accustomed to waiting patiently for decompression.

During the long delay between the closing of the caisson and the putting on of the air, the teredo had been very busy in some of the exposed parts of the caisson. It was necessary to remove some of the bulkhead timbers within the rings entirely, but most of those in the working chamber stood up to the work, the holes being afterward pumped full of grout with the grouting machine. The caisson itself was strained slightly by the turning, and a few of the caulked joints in the working chamber opened slightly.

No special difficulty was experienced in mudding up these leaks, although they required constant attention, and together with the worm holes caused a considerable blow-out of air on the southeast corner. This leak was not regarded entirely as an objection, as it served to keep the air in the working chamber in good condition, and taken as a means of ventilation not requiring more air than would have been otherwise wasted, no strenuous effort was made to close it. In addition to the porous sand stratum below the blanket of mud at the bottom of the bay absorbed a large volume of air, and in calm weather the bubbles of air could be seen rising in all directions for a long distance from the work.

After the concrete was started the work never stopped night or day until the working chamber was filled with concrete, sealed and the air taken off. During 1906, and until August, 1907, the work was carried on with a small force working only one shift. The main volume of concrete was placed by three shifts working throughout the 24 hours, and for considerable periods, the material handled averaged a cubic yard in each six minutes. After the concrete reached the surface of the water, one shift easily placed the material as fast as the caisson sank.

In filling the working chamber all but the last few yards of concrete at the bottom of the central air shaft was dropped through two 12-in. diameter iron pipe shafts leading through the north and the south dredging shafts. These pipes were installed when the temporary doors were put in the shafts, and built in the concrete as it came up. A 12-in. Jenkins straightway back-pressure valve was placed at the top of each to hold the pressure and act as a lock. A wooden target with a rubber gasket was used at the bottom of the pipe to hold the air, when the top valve was opened to fill the pipe with concrete from the hopper platform. Means were provided to equalize the pressure with the main air shaft, and the arrangement worked reasonably well. Some trouble was experienced from stoppages due to the long length and small diameter of the pipe. It proved that for tubes for this purpose, particularly if as long as these, 84 ft., the diameter should be not less than 16 in., and 18 or 20 in. would probably give better results.

Outside of the small boiler on the barge, four boilers were used; two of them were of the marine type of 125 h.-p. each and the other two were verticals, aggregating about 100 h.-p. Two Class A straight line Ingersoll-Rand compressors were used, one high-pressure machine of 1,250 cu. ft. per minute, and the other a low-pressure machine of about 900 cu. ft. free air per minute. Air receivers and an air cooler made up of 6-in. pipe carried through a tank of water under the pier were provided, and the conditions in the caisson so far as the air was concerned were at all times pleasant and agreeable.

A 12½-kw. generator and engine was installed. The lights for all the houses and around the outdoor machinery, and also those in the locks, shafts and caisson, as well as the arc lamps for general illumination, were attached to this machine.

The number of men employed during the last few weeks averaged 115. There was no special sickness and only two or three men were sent away from the wharf on that account. No one was seriously injured and there were but two slight casualties during the progress of the work. The reasons for this happy condition Mr. Wood attributes to the care exercised in picking out and looking after the men, to the short shifts, which aided in keeping up their vitality, and to the entire lack of means for dissipation on the part of all employed. The rest and food were factors, as was also the care taken in securing a pure air supply; the ventilating and lighting of the air chamber also aided. The provision of only small openings on the man lock, which made it absolutely impossible for any of the men to do otherwise than observe the rules of the best practice for compression and decompression in entering and leaving the caisson was undoubtedly of value.

Taking into account the number and character of the men employed, the length of time for which they were engaged, the hazardous nature of the work, the remote location and narrow limits within which a large number of men labored and were housed, fed and cared for, the operation is remarkable, and in this phase of it Mr. Wood takes a great deal of pride. For the rest he declines to assume all the credit, claiming that for the success attained he is in part indebted to Mr. John R. Bland, president, and Mr. J. Kemp Bartlett, vice-president of the United States Fidelity & Guaranty Co., for their unstinted support and co-operation; to Col. R. L. Hoxie, Corps of Engineers, U. S. A. Light-House Engineer, and to Mr. Murdock, his assistant, for their interest and consideration at difficult points; to Mr. Sangemeister, the chief draftsman in the Light-House engineers' office, who worked out the plans for the structure; to Mr. W. C. Flannery, the superintendent during the righting of the caisson; to Mr. J. A. Prout, engineer and superintendent; to Mr. M. S. Stokes, superintendent on the concrete and compressed air work; to Mr. F. C. Arthur, U. S. Inspector on the work; to Capt. Fred Lankford, assistant superintendent from the beginning to the end, and Dr. J. A. McCort, the medical director, all of whom aided with many of the practical suggestions, which were adopted and carried out. Mr. Wood also acknowledges his great indebtedness to the men who, through long nights and days of strain, stress and struggle, in intense heat and bitter cold, in calm weather and with gales blowing, often at the risk of life and limb, performed their part. As he expresses it: "No matter what his ability, no man gets very far or does very much except through the loyalty and co-operation of those on whom he depends to execute his ideas. Therefore after everyone else has been given full credit, what is left you may award to me," a somewhat unique and rather unusual point of view.

Rock Excavation on the Clyde.

The deepening of the Clyde Channel to a minimum of 28 ft. below low water of the spring months was completed last year, by the removal of rock from the Elderslie reef over an area of 5½ acres. The removal of this reef was started in 1886 when the minimum depth at low water was only 14 ft. The channel was deepened to a minimum of 20 ft. by the removal of 110,000 tons of rock. In 1903 it became necessary to further increase the depth of the channel and contracts were let to Messrs. W. Hill & Co., London, for the removal of an additional ledge of 8 ft. In order to locate the work two parallel rows of poles about 300 ft. apart were set up on base lines on the bank of the river, the poles in each row being on 25-ft. centers. At first the drilling of the rock was accomplished from a barge within which was a caisson that could be lowered and raised by steam winches. The caisson was large enough to accommodate six or seven men, and contained six Ingersoll-Sargent compressed-air rock drills. When at work in the river, the position of this barge was regulated from the bearings of the poles or stakes already described on the south bank, and its distance from the base line was measured by means of a wire rope with marks every ten feet, wound or unwound as required by a reel on the deck of the barge. Owing to the difficulty of steadying the caisson on the uneven bottom, and the limit to the lengths of the boring rods which could be used in the caisson, this mode of working was found to be unsuitable, and the contractors provided barges equipped with Ingersoll percussion drills suspended along one side of the barge by chains passing over pulleys on the top of an iron framework. The drills were slung in guiding frames, leaving them free to move up or down as required, but not laterally. The boring operations in the earlier stages had been carried out in patches, careful record of which was kept on charts both by the contractors and the engineer of the Clyde Trust, but later it was decided to conduct all the boring and blasting operations in belts, as had been adopted in the former contract of 1886. The belts covered a width of 15 ft., with six rows of holes in each belt. These rows were 2½ ft. apart, and the holes, which were spaced 5 ft. apart longitudinally, were opposite each other in the alternate rows. This mode of working provided a free side or face, and allowed the dredger to follow the boring barge and lift the broken rock, and clean up the surface of the next belt to be bored. For the most part the depth of rock had to be bored, blasted, and dredged in at least two breaks or depths. Under this system the work progressed much more rapidly, and, as the boring was carried to a depth of 30 ft. to 31 ft., below low water, dredging was easily accomplished to the desired depth of 28 ft. below low water. In order to be certain that the minimum depth was secured throughout, a diving bell went over the entire bottom. During the contract 38,240 holes were drilled to an average of 6 ft. The dynamite was lowered into the holes enclosed in a zinc canister. The total amount of rock removed was 340,520 long tons.

The Removal of a Tall Steel and Brick Smoke Stack.

At the Lorain plant of the National Tube Works, a steel smoke stack 225 ft. high and 11 ft. in diameter, lined with brick, 14 in, 9 in., and 4½ in. in thickness from the bottom upwards, was seated on solid rock with a brick foundation about 22 ft. in diameter and 30 ft. high above the surface of the ground, to which the stack was secured by heavy anchor bolts through its spread base, thus making it stable without guys.

This stack had served a group of gas furnaces for which a new stack had already been built, and it was important that it should be removed as quickly as possible to allow for the completion of the skip-hoist without which the new furnaces could not be put in operation. It was also very important that the bricks should be handled from the inside and that there should be no danger of injury to the numerous workmen engaged in the immediate vicinity. The fire brick lining was valuable, and it was desirable to secure as much salvage from it as possible.

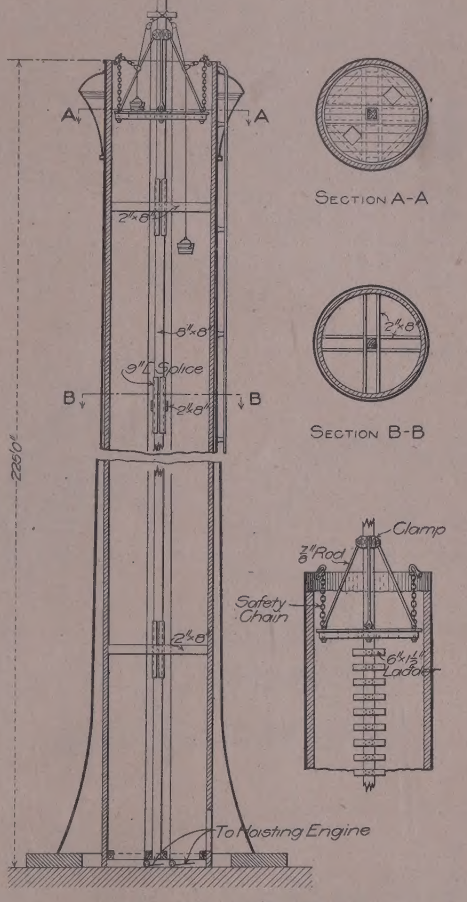
It was, therefore, decided to take down the stack from the inside, and for this purpose several of the steel shell plates were removed at the base and an opening made through the brick work in which 8 x 8-in. timbers 20 ft. long, previously prepared, were inserted. Each timber was furnished at the upper end with a splice consisting of a pair of 9-in. channels 7 ft. long bolted to it, flanges in. Access to the top of the chimney was afforded by an exterior spiral staircase reaching half way up and by a ladder for the remainder of the distance. A hand-line was lowered from the top and first a light tackle and then a heavy one was hauled up, and a timber was hoisted and temporarily placed across the top of the stack, from which the tackle was suspended and the 8 x 8-in. timbers were hoisted inside.

As fast as each timber was hoisted to a vertical position, the lower end was dropped in the jaws formed at the top of the previous timber by the splice channels, and there bolted until finally the 8 x 8-in. timbers formed a continuous mast essentially equivalent to a gin pole 240 ft. high, projecting 15 ft. above the top of the chimney and securely wedged and braced and seated at the bottom on a timber sill.

In the bottom of the chimney a horizontal circular platform was contstructed with a clearance of about 3 in. from the inner walls, and was hoisted to the top of the chimney by a tackle attached to the upper end of the 8-in. timber. This platform was made with center clearance for the pole, and was hoisted to within 5 ft. of the top of the chimney, where it was supported additionally by four safety chains from the upper edge of the chimney shell. The mast was braced intermediately by sets of double 2 x 8-in. radial strips at right angles to each other nailed across it about 20 ft. apart vertically on alternate faces and engaging the interior walls of the chimney.

A double-drum hoisting engine was located on the ground near the foot of the chimney and lines from it led up through the chimney over the sheaves at the top of the pole, and operated two half-barrel buckets in which the brick furnished by the demolition of the lining were lowered through trap doors in the bottom of the working platform. After the brick was taken down to the platform level, the rivets were cut out of the steel plates in the shell of the stack and the buckets being disengaged from the hoisting lines, the latter were attached to the plates and they were lowered on the outside of the stack.

After work had been well commenced it was found that the safety chains provided to support the platforms from the chimney shell were unnecessary and that even if the tackles supporting it from the top of the mast were released it would be held in position by the 6 x 1½-in. cleats nailed across the mast to serve as an emergency ladder. As fast as each 6-ft. course of the chimney was removed, as above described, the platform was lowered 6 ft. by its tackles from the top of the mast, another course of bricks and steel plates were removed, and so on for about 30 ft. The platform was then secured temporarily by the safety chains and a man climbed to the top of the mast, lowered the tackles to the platform, and about 20 or 30 ft. of the mast was then cut off, leaving it projecting at least 10 ft. above the platform, when the tackles were again connected to it and the operations were repeated. Three ten-men eight-hour shifts were employed continuously for two weeks in removing the chimney, about one-half of the time being necessary to cut out the rivets in the steel plate. All of the bricks were saved in good condition, so that they were available for rebuilding.



Falsework and Tackles.

The contract time allowed only three weeks for the execution of the work, and it indicates the care and efficiency with which it was accomplished is indicated by the fact that in two weeks the work was entirely completed without any accident or injury to surrounding property.

The work was designed and executed by John Eichleay Jr. Co., Pittsburg, Pa. Mr. J. P. Eichleay being in personal charge of the work. F. W. Waterman was the Tube Co.'s engineer in charge.

An Unusually Large Engine installed by the C. & G. Cooper Co. at the billet mill of the Duquesne Steel Works has 42 and 74-in. by 60-in cylinders. The valve gear has the inlet cranks direct-driven from rock arms without the use of wristplates, while the exhaust valves are operated from wristplates. The admission and exhaust motions are actuated from separate eccentrics. The governor is driven by three 1-in. ropes with a tension device which will close the admission valves if the ropes break or slip. The engine has a 25-in. hollow bored crank shaft with a 27-in. wheel seat for a 22-ft. fly-wheel weighing 52,000 lb.

A Concrete and Earth Diversion Dam in California.

The John Days diversion dam on the South Fork of the Eel River in Mendocino County, California, is a concrete and earth structure having a total length of 630 ft. on top. The concrete portion of the dam is a gravity-section spillway, 350 ft. long at the crest, and with a maximum height of 73 ft. The balance of the dam is an earth embankment, having a thin concrete core wall to prevent percolation and the burrowing of animals. Owing to the character of the stream on which the dam is built, and to the foundation conditions existing at the dam site, the design involves various features of interest.

The Eel River has a watershed above the dam site of 324 square miles of broken, mountainous country. No flood or rainfall records in regard to this watershed were available when the dam was designed, except rainfall observations for two and one-half months at the dam site and three stream-discharge measurements at the same point. Since such a lack of records frequently exists, especially in the western part of this country, the method used to arrive at the necessary capacity of spillway is worthy of explanation.

The only rainfall or stream-flow information relating to the situation, aside from that mentioned above, were continuous rainfall records at Ukiah, 22 miles southwest and at Willits, 20 miles west, for a number of years preceding and including the two and one-half months during which rainfall records were taken at the dam site; and the flow-lines of maximum floods as indicated by debris-marks. Since it is well known that in California rainfall intensities often vary greatly in short distances, the only use to which the Ukiah and Willits rainfall records could be put was to establish relations between them and the rainfall of the area above the dam site.

A careful study, in connection with the determination for power-consideration of the least yearly rainfall above the dam site, showed that the rainfall at John Days was about 140 per cent. of that at Ukiah and about 75 per cent. of that at Willits. The rainfall at Willits is about 160 per cent. of that at Ukiah, so the John Days rainfall, in terms of the Ukiah, is 140 per cent., if deduced from the Ukiah, and 120 per cent. if from the Willits records. The mean, or 130 per cent., was accepted as a fair relation between the rainfall at John Days and that at Ukiah. The relationships were established by careful comparisons of the daily rainfalls at John Days, Ukiah and Willits, using the daily records cumulatively and otherwise. The 130 per cent. relation established is for the dam site, the lowest point of the watershed, and for periods of ordinary rainfall. For spillway considerations only maximum rainfalls need be considered and for such rainfalls, and also for the more mountainous areas constituting the drainage-area above the dam site, it was assumed that double the rainfall at Ukiah must be considered probable.

Three independent methods were employed to check the spillway-flow for which provision should be made. The maximum probable flow was estimated, first, from the debris marks; second, from the maximum rainfalls; and third, from a consideration of the maximum known rates of flow per square mile on other drainage areas.

The debris marks were made use of in two ways; first, by computing the discharge by the Chezy formula, $v = c\sqrt{rs}$, and second, by a somewhat novel way to be described. In the first way the coefficient n was assumed 0.035, the slope was that shown by the debris, and the hydraulic radius was for the section below the debris marks. Four sections, equally spaced over 300 ft. of the stream, were considered and the flows thus computed were, for the two middle sections, 114,000 and 138,000 cu. ft. per second, respectively. The corresponding mean velocities were, however, 35.0 and 35.5 ft. per second, beyond all reasonable limits. The probable explanation is that the flow causing the debris marks was not a case of "uniform flow," to which class alone the Chezy formula applies; and hence the slope shown by the debris marks was not indicative of the true velocity.

The second use made of the debris marks was in connection with the three meter gagings which had been made at these sections, showing actual flows of 7,735, 1,300 and 998 cu. ft. per second, respectively. In these gaugings the velocities were measured directly and the hydraulic radii were derivable from the plotted cross-sections; and when plotted on rectangular coördinates, with the mean velocity and the hydraulic radius values respectively as ordinates and abscissas, the three points were found to lie in a practically straight line and to give a relation: mean velocity = 0.85 + 0.62 × hydraulic radius.

This formula, applied to sections below the debris marks, gave flows for the two intermediate sections of 39,000 and 33,000 cu. ft. per second, respectively, with corresponding velocities of 9.4 and 8.4 ft. per second. These velocities are entirely reasonable and probably not greatly in error. It also seems that this method of computing maximum flood-flows from debris marks and measured lower flows may often be much more reliable than the ordinary one making use of the sections and slopes shown by debris marks. The hydraulic radius is the most characteristic of any element of a section; and the necessity of selecting a coefficient *n* and a slope is avoided. Whether such a plotting of points result in a straight line or a curve, it would seem that higher values of velocity obtained by projection would be more free from arbitrary assumptions and probably much nearer the true, but unknown velocity, than would be results obtained by using the Chezy formula in connection with the debris marks.

The great disparity between the results obtained by the above two methods, also the uncertainty as to whether the debris marks were from the absolute maximum flood, made it necessary to check the maximum discharge in other ways. For this purpose general considerations of rainfall and runoff were used.

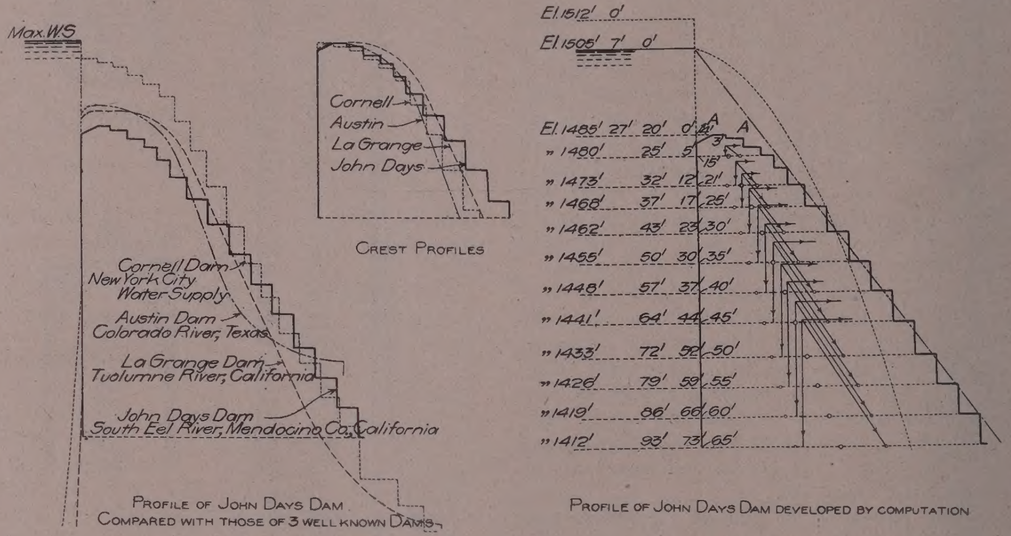
The first element in the rainfall consideration was naturally that of the maximum rates of rainfall which have occurred at the nearest long-period rain-gauge stations. The only daily records available were those at the town of Ukiah, 22 miles from the site, and these were for only 11 years prior to the design of the dam. These records showed that on Jan. 13, 14 and 15, 1894, the rainfall at Ukiah was respectively 0.40 in., 5.30 in. and 1.41 in. It was of course probable that during some 24 consecutive hours, beginning on January 14 and ending January 15, a precipitation occurred materially in excess of the 5.30 in. recorded for January 14. The principal other recorded high rates of rainfall were on January 3 and 4, 1895, and on January 2, 3 and 4, 1901. On the two former dates, 1.75 in. and 4.07 in. of water fell, respectively, and on the three latter dates, 1.21 in., 4.40 in. and 0.85 in., respectively.

As before explained, the maximum rainfall for the area above the dam site is probably double that at Ukiah. From the available records this would give a probable maximum rainfall of 10.6 in. in 24 hours. In this connection it is notable that the Lick observatory on Mount Hamilton, in the same mountain-range, but about 150 miles south of John Days, with a mean annual rainfall less than that of Ukiah, has a recorded maximum storm as follows: 1884-Dec. 19 = 4.86 in.; Dec. 20 = 3.14 in.; Dec. 21 = 9.05 in.; and Dec. 22 = 2.35 in. The 0.4 in. of rain at Ukiah on the day preceding the heaviest rainfall there, and the two days of heavy rainfall at Lick observatory before the day of the maximum rate, make it probable that the runoff on days of maximum precipitation equalled the rainfall in both cases.

It was therefore considered that a runoff of as much as 10 in. in 24 hours from the catchment area of the Eel River in the 11 years preceding the construction of the dam was not improbable. Such a rate of daily runoff equals 7,540 millions of cubic feet for the 324 square miles of catchment area, or an average of 87,300 cu. ft. per second for the 24 hours. Previous experience with floods on catchment-areas of streams in the same mountain-range had shown that the maximum rate of a flood on such streams is about 50 per cent. greater than the average of the maximum 24 hours. This condition gives a maximum flood-rate for the Eel River catchment-area of perhaps 131,000 cu. ft. per second.

Warm rains falling on heavy snows also occasionally increase the runoff from this catchment area. One instance of this kind is known when 18 in. of wet snow fell in three days and was immediately followed by three days of heavy, warm rain which melted the snow in about two days. The volume of water produced by such a combination of conditions is naturally large.

The final general consideration in fixing the maximum rate of flood which might occur was the maximum rate per square mile which had been observed in other catchment-areas. The South Fork dam near Johnstown, Pa., failed under a flood which at its maximum reached 215 cu. ft. per second per square mile. One authority on stream flows in the West, states that sudden great storms in that region may cause a maximum flood discharge, for short periods of time, as great as 300 cu. ft. per second per square mile of catchment area. It has also frequently been advised for works in the vicinity of Boston and New York that spillways be proportioned to discharge a runoff equal to 6 in. per 24 hours over the entire watershed, which is several times the largest measured rainfall in that locality. The 131,000 cu. ft. per second deduced as shown is equivalent to 405 cu. ft. per second per square mile for the 324 square miles of catchment-area above the John Days dam. A rate of 300 cu. ft. per second per square mile gives 97,200 cu. ft. per second for the whole area. Theory, observation and practice, however, were believed to indicate that 100,000 cu. ft. per second, which is at a rate of 309 cu. ft. per second per square mile, was a reasonable allowance for floods in proportioning a spillway for the large though practically unknown catchment-area above the dam.



Profile of John Days Dam Compared with those of 3 well known Dams

Crest Profiles

Profile of John Days Dam developed by computation

Profiles of John Days Dam and Others of Similar Section.

Foundation and topographical conditions limited the length of the spillway that could be safely and economically built. The channel of the river was rock, the surface of which was irregular, transversely with the stream. The rock rose on one side of the channel, but dropped away quite abruptly on the other side, the river bank on that side being of earth to a considerable depth in an ancient channel. One end of the spillway was thus limited to the point where the abrupt drop in the rock occurred, and the length of the spillway was dependent on the amount of rock excavation which could be done economically on the other side of the channel. The volume and length of this rock excavation was governed, as nearly as practicable, by the amount of crushed stone needed for the concrete.

Based on these conditions, it was found practicable to secure a spillway at least 350 ft. in length, about 80 ft. of which at one end would be in the rock excavation. The Francis formula for discharge over wide-topped weirs, $h = \sqrt[1.53]{Q \div (3.01 \times l)}$ in which h = depth in feet of water over the crest, Q = discharge in cubic feet per second and l = length in feet of spillway, was used to determine the depth of water over the crest. This h was 19.63 ft. for the assumed maximum flood of 100,000 cu. ft. per second. No reduction in depth of spillway was made on account of storage in reservoir above the spillway-lip, as the reservoir was small and a flood of 100,000 cu. ft. per second would discharge freely over the spillway and at the same time raise the water in the reservoir to a height of 20 ft. above the crest in one hour and 50 minutes.

In fixing the dimensions of the spillway, however, provision was made for the possibility of floods in excess of 100,000 cu. ft. per second. With the 350 ft. of spillway that could be made available, 100,000 cu. ft. per second would cause the depth of 19.63 ft. on the spillway, or in round numbers 20 ft. To this there were added 5 ft. for waves on the reservoir and 3 ft. simply as a further safeguard. A 23-ft. overflow depth would allow a discharge of 127,000 cu. ft. per second and a 26-ft. overflow depth, with 2 ft. allowed for waves and no added safety provision, a discharge of 153,000 cu. ft. per second or at the rate of 472 cu. ft. per second per square mile. In addition, the final plans provided a spillway 355 ft. in length. It is believed that, even though the maximum flood-conditions are unknown, the spillway provisions are thus ample for any contingencies which may arise. It is worthy of mention that within six months after the plans were made a measured flood having a maximum rate of 46,000 cu. ft. per second passed over the uncompleted dam.

At the end of the spillway section, close to the drop in the surface of the rock, a long wing-wall was built parallel with the river channel to retain and protect the earth-embankment section. This wing-wall and the embankment were built to a height of 28 ft. above the crest of the spillway, 20 ft. for floods, 5 ft. for waves and 3 ft. merely as an extra precaution. This unusual depth of spillway and provision for floods entailed in this instance only a small additional cost, as the entire embankment contains only 17,000 cu. yd. of earth and the wing-walls only 4,130 cu. yd. of concrete, only small proportions of which could have been saved by a few feet less depth of spillway notch.

In designing the cross-section of spillway it was assumed that during the maximum probable flood the crest would be overtopped by water to a depth of 20 ft. The assumption was also made that if the falling sheet of water should shoot clear of the downstream face of the spillway, the additional horizontal pressure against the latter produced by the resulting partial vacuum would be equivalent to that from an addition of one-third to the assumed maximum depth of water over the crest. The section of the spillway is therefore proportioned for pressures resulting from a water surface 27 ft. above the crest of the dam, 20 ft. from floods and 7 ft. for the added one-third due to the extreme possibility of the water passing free from the downstream face. The weight of the water directly over the spillway was neglected, as was also the effect of backwater below the spillway, though the surface of the back-water is only 45 ft. below the spillway crest, even at low stages. These severe assumptions and the 7 ft. added to the pressure were largely from a recognition of the more severe conditions, in comparison with an ordinary impounding section, to which a spillway section is subjected. The further assumption was also made that there would be no upward hydraulic pressure on the base of the dam. Since a rock abutment could be secured at only one end, no additional strength was to be gained by making the spillway portion of the dam curved or arched in plan. It was therefore built on straight lines, with one angle, following the highest lines of the site and thus saving masonry.

The computations for the design of the spillway section were made by the usual methods for computing gravity-section dams. These methods were believed to be so generally accepted, and dams designed in accordance with them to have been so generally successful that they were considered as standard. Computations were made of the forces and weights acting above parallel base planes, as shown by elevations in the first column of the accompanying Table I, and for a transverse vertical section or lamina of the dam 1 ft. wide. Each of these base planes is at the foot of a step on the downstream face of the dam, and seventeen dimensions, forces and stresses were computed for it. The elevation of the base plane and the corresponding thickness of the dam shown in the first column were assumed and computations made, then, if neecssary, new assumptions and computations were made until the "middle-third requirement" was satisfied. The values given in the second to the seventh columns, inclusive, were derived by ordinary methods. The values in the remaining columns were computed as follows, the numbers in parentheses representing corresponding values in different columns:

Column $(8) = \frac{1}{2}(1) - (3)$; column $(9) = (3) + [(6) \times \frac{1}{2}(5)] - \frac{1}{2}(1)$; column $(10) = \frac{1}{6}(1) - (8)$; column $(11) = \frac{1}{6}(1) - (9)$; column $(12) = (2) \div (1)$; column $(13) = (12) \times [(1) + (6) \times (9) \div (1)]$; column $(14) = (12) \times [(1) + (6) \times (8) \div (1)]$; column $(15) = (4) \div (7)$; column $(16) = (5) \div (1)$; column $(17) = (5) \div (2)$.

Various requirements of design were fixed in advance, these requirements, except the shearing stress, being selected from different recommendations for the Cornell dam of the New York City water-supply system. Owing to the small height of the John Days dam, the maximum water-pressure considered was equivalent to only 100 ft. in depth and the specified limits of pressure were not approached. The various requirements are as follows: (a) The lines of resultant pressures must lie within the middle third of the base for all base planes, whether the reservoir is full or empty. (b) The factor of safety against overturning above any base plane must not be less than two. (c) The water pressure against the back of the dam above any base plane shall not be more than two-thirds the weight of the masonry above that plane, or in other words, the sliding or shearing coefficient shall be less than two-thirds. (d) The shearing stress in any base plane shall not be more than 8,000 lb. per square foot, this being about one-half the allowable stress in compression. (e) The maximum computed vertical pressure in any base plane shall not exceed 16,000 lb. per square foot for the downstream, and 20,000 lb. per square foot for the upstream face. The limiting pressures adopted in this case are not very important, as the small height of dam restricts the maximum pressures below even these low limits.

The computed values to be compared with the five requirements are all contained in Columns 10 to 17 of accompanying Table I. From these it is evident that the requirements are practically met by the section adopted. At the same time, in the case of the reservoir empty the center of gravity is so far within the middle third of the base as to appear uneconomical. This is unavoidable, however, as the absence of masonry weight for the upper 27 ft. of water-pressure with the reservoir overflowing makes it impossible to keep the resultant near the limit of the middle third when the reservoir is empty. The requirement that the sliding coefficient be less than two-thirds is also apparently not satisfied for the upper 44 ft. of the dam. This cannot be remedied, either, due to the same lack of masonry weight, but an additional weight of 8,900 lb. of overlying water such as would be occasioned by a mass of water 20 ft. deep and 7 ft. wide will bring the worst case within the specified limits. This condition, which would be close to the fact, and the small shearing stress in the upper part of the dam, together with the climatic impossibility of ice-forces, were believed to make it permissible that the sliding coefficents be somewhat less than two-thirds for the upper portion of the section.

The profile cross-section of the spillway of the John Days dam is compared in an accompanying illustration with the profiles of three other well-known dams in this country. These three dams were all built of large-block rubble masonry, which is stronger and heavier than the concrete used in the John Days dam. Furthermore, the Cornell dam is, and the Austin dam was, faced on both the upstream and the downstream sides with large-block cut-stone masonry. The comparative strength and safety of the John Days dam are therefore somewhat less than indicated by a comparison of the profiles only.

The choice between a stepped and a smooth downstream face for an overflow dam was considered to be largely a matter of individual preference, since there are many instances of both forms in successful use. The smooth face is held to save wear on the dam at the expense of permitting wear on the river bottom; while, on the other hand, the stepped face reduces the scour in the river bed, although the steps are probably not very effective in this way except for low overflows. The principal reason for the choice of steps for the face of the John Days dam was a greater convenience and simplicity in the use of forms during construction.

The wing-wall which separates the spillway section from the earth-embankment section cannot be considered merely an auxiliary structure in this dam. In fact, it is so important that its failure would probably be followed by large slides in the embankment, a failure of the core-wall and the eventual passage of the whole flood through the embankment section and a change of the river to its ancient channel. No attempt was made, however, to fix the section of the wing-wall by computation, as no satisfactory method of making such computations was considered to exist. The section chosen was made 5 ft. wide on top and with a 1 to 6 batter on both sides. This section is somewhat thinner than the well-known Trautwine sections, because practice at the Titicus and Cornell dams of the New York water supply system was taken to justify such a reduction; and also because it is known that considerable masonry can be removed from the back of a retaining wall without causing much consequent reduction in stability. The section was made

TABLE I.—RESULTS OF COMPUTATIONS

WEIGHTS AND FORCES FOR SECTION OR LAMINA OF DAM 1 ft. IN LENGTH

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Base-Plane under consideration	Thickness of Dam just above Plane ft.	Tot. Wgt. of Mas'y above Plane per lin. ft. of Dam lb.	Dist. Cen. Grav. of Mas'y from up stream edge of Dam ft.	Resist. Mom. of Mas'y about down-stream edge ft.-lb.	Total Pressure of Water above Plane lb.	Dist. above Plane of Cen. Pres. of Water ft.	Overturn'g Mom. of Water about Down-stream edge ft.-lb.	Dist. Cen. Grav. of Mas'y from Middle point of Base Plane ft.	Dist. of Interst't of Result of W and P with Plane, from Mid. Pt. of Plane ft.	Dist. Cen. Grav. of Mas'y falls within Middle Third of Base Plane ft.	Dist. Result of W and P falls within Middle Third of Base Plane ft.	Aver. Vert. Pressure per sq. ft. on Base Plane from Wgt. of Mas'y lb.	Max. Vert. Pressure per sq. ft. (on down str. edge) with water surface @ El. 1505' lb.	Max. Vert. Pressure per sq. ft. (on up-str. edge) with no water in reservoir lb.	Factor of Safety against Over-turning	Shearing Stress per sq. ft. of Base Plane lb.	Sliding Coefficient
El. 1,480	15	8,250	6.78	67,700	9,220	2.43	22,400	0.72	2.00	1.78	0.50	550	990	709	3.02	615	1.12
" 1,473	21	29,000	9.02	347,500	24,700	5.65	139,000	1.48	3.32	2.02	0.18	1,380	2,693	1,963	2.50	1,177	0.85
" 1,468	25	47,700	10.38	697,000	37,750	7.84	295,000	2.12	4.08	2.05	0.09	1,909	3,780	2,880	2.36	1,510	0.79
" 1,462	30	74,700	12.04	1,339,000	55,300	10.37	574,000	2.96	4.72	2.04	0.28	2,490	4,845	3,965	2.33	1,843	0.74
" 1,455	35	111,600	13.85	2,356,000	78,700	13.22	1,041,000	3.65	5.68	2.18	0.15	3,190	6,290	5,180	2.26	2,246	0.71
" 1,448	40	153,500	15.51	3,760,000	105,200	16.00	1,626,000	4.49	6.51	2.18	0.16	3,840	7,590	6,420	2.31	2,620	0.69
" 1,441	45	200,800	17.18	5,590,000	134,700	18.70	2,520,000	5.32	7.22	2.18	0.28	4,470	8,770	7,635	2.22	2,990	0.67
" 1,433	50	260,700	18.98	8,090,000	172,300	21.75	3,750,000	6.02	8.33	2.31	0.00	5,214	10,428	8,990	2.16	3,446	0.66
" 1,426	55	319,000	20.50	11,000,000	208,300	24.37	5,080,000	7.00	8.91	2.17	0.26	5,800	11,440	10,240	2.17	3,790	0.65
" 1,419	60	381,700	22.06	14,480,000	247,800	26.94	6,680,000	7.94	9.53	2.06	0.47	6,360	12,430	11,400	2.17	4,120	0.65
" 1,412	65	449,500	23.70	18,550,000	289,700	29.50	8,540,000	8.80	10.21	2.03	0.62	6,920	13,450	12,550	2.18	4,460	0.65

thicker than the wing-wall at the Cornell dam, however, because, being of concrete, it is both lighter and weaker in proportion than that wall, and also because it is subject to the shock and action of floods, which is not the case at the Cornell dam. The 1 to 6 batter on the back face of the wall was adopted in order to secure a slight vertical pressure from the embankment and thus increase the stability of the wall to some extent.

The wing-wall has a total length of 185 ft. and an extreme height of 50 ft. The top is level for a length of 10 ft. at the crest and is on a 1 to 3 batter upstream and 1 : 2½ batter downstream from the dam. The wall is built on rock, except for a length of 75 ft. at the upstream end, where it is on earth. Where rock foundations were obtainable, the rock was blasted out in such manner as to give the outer toe of the wall a slight penetration to prevent sliding. On earth foundation the bottom of the wall was sloped down from the front to the back and a shoulder, 15 in. wide and 3 ft. thick, was built at the outer toe for sections above 20 ft. in height. In order to reduce pressures on the wall, the surface of the steep hillside behind it was cut in steps before the embankment material was placed. For the same reason, the material was placed in layers inclining upward to the wall and was thoroughly wet and compacted while being placed.

The earth embankment is 10 ft. wide on top and has slopes corresponding to the slopes of the wing-wall, 2½ to 1 on the downstream, and 3 to 1 on the upstream side. The upstream slope was rip-rapped to a vertical height of 5 ft. above the expected maximum flood-level to avoid damage from wave-action. The toe of a portion of the downstream slope is below the maximum water-surface on that side and is also rip-rapped. In addition to the protection against percolation afforded by the concrete core curtain wall, four trenches were excavated at about equal distances apart in the natural ground under the site of the upstream side of the embankment. Three of these trenches are parallel to the core wall and the fourth is near and parallel with the toe of the embankment.

The core wall is on a rock foundation for about 35 ft. from the wing wall, and in this length is 4 ft. wide on top, with a batter of 1 in. to 1 ft. on both faces. The remainder of the wall is on a sandy earth foundation, and consists of an 8-in. concrete curtain wall, re-inforced with a layer of expanded metal, on a concrete base 3 ft. wide and 2 ft. deep. This thin portion of the wall has its base in a trench varying from 15 ft. below the natural surface, where the earth foundation starts, to 3 ft. at the outer end of the wall. At the dividing point between the earth and rock foundations a well, 2 x 4 ft. in cross section, was extended from the top to the bottom of the wall. This well was provided to cause a weakness in the wall where the foundation changes, thus localizing the cracking likely to be caused by settlement of the earth foundation. After the embankment had been completed, as the settlement had probably nearly ceased, the well was filled with soft concrete. This detail is copied from a similar one employed by the late Mr. Alphonse Fteley in the Titicus dam of the Croton water supply system of New York City.

The dam was designed by Mr. Edwin Duryea, Jr., consulting engineer, of San Francisco, to whom this journal is indebted for the detailed information presented herewith, which is taken from drawings and notes embodying the design. The larger portion of the construction of the dam was carried on in the fall of 1905, but due to a suspension following the San Francisco fire, the dam was not finally completed until the summer of 1907.

Concrete Highway Culverts and Bridges in Iowa.

Some statements recently presented to the Iowa Engineering Society by the Iowa State Highway Commission indicate that concrete structures will be introduced on road improvements in Iowa in 1908 more extensively than during any previous year. It is pointed out in this connection that the location will in a large measure determine the form and design of the structures, for the different glacial areas of the State present very different and greatly varied conditions. For instance, in that part of the State lying south of the main line of the Rock Island R.R., there are numberless water courses with branches reaching into almost every quarter section of land. These, while dry during most of the year, during wet periods become small but very wild little streams whose action carries destruction to the flimsy wooden culverts and small bridges now generally used. The watersheds are in general steep and the water reaches the stream courses quickly and is as quickly gone. In such places concrete culverts with wing walls are peculiarly adapted to the location, and in many cases a small culvert will replace a fair-sized bridge. The Commission replaced, in one instance, a 20-ft. wooden bridge with a 2 x 3-ft. culvert, which has since carried off the water satisfactorily during one of the heaviest storms that locality has experienced in recent years.

There is another kind of topography along each of the Iowa boundary rivers, which is very rough. In the western part of the State the streams flow in a general southwesterly direction somewhat parallel to the Missouri. Tributary to them are many smaller creeks and streams which have narrow valleys with steep slopes to the highlands on either side. These valleys are subject to occasional heavy storms, confined often to the valley limits, and the water courses are deep cut, being in many cases 25 to 30 ft. from the ordinary flow-line to the floor of bridges over them. A single storm may carry away wooden structures, for miles along a stream. In such places heavy arch or flat-topped culverts of 12, 16 or 20-ft. span have proved satisfactory when subjected to severe tests.

In the north, central and eastern sections of the State, the stream gradients are comparatively flat, the water courses are tortuous and the bank on at least one side is low. For these streams the slab or girder type of culvert seems preferable, as the headroom is limited and usually the streams will be out of their banks and flowing over the road grades before rising very much. A waterway sufficient to take the ordinary flow is entirely adequate.

In the use of cement and concrete the character of the material should always be kept in mind. The first cost of concrete like any other masonry should be the total cost, and so far as this kind of construction is employed, it should be designed and constructed with a view to developing its "masonry properties" rather than its "structural steel" properties. Thin, flimsy sections have no legitimate field in the improvement of highway bridges which are being subjected to the constantly increasing traffic both in volume and height.

Concrete for bridge floors is a new use of this material to most sections of the State, but it is now beginning to find favor in some counties, and will undoubtedly increase in importance. When it is considered that the life of plank bridge floors on main traveled roads is only three to five years, some idea may be gained of the desirability of adapting bridges to a heavier but more permanent floor material. In Illinois this plan has been very successfully used. The Iowa Highway Commission is now designing some steel structures with such floors. The material required for the floor and curbs of a 60-ft. steel bridge is about 17 yd. of reinforced concrete.

The largest failure of concrete work in the State during 1908 was that of a 45-ft. girder-type reinforced concrete bridge in Hancock County. The bridge was completed about the middle of September and the forms taken out sometime about Dec. 5. Prof. Thos. H. MacDonald, highway engineer of the Commission, visited the site on Jan. 3, but the structure was so completely demolished that any very definite facts could not be observed.

The structure apparently had consisted of two girders each 18 in. wide by 7 ft. deep by 45 ft. long, reinforced by fourteen 1-in. round steel rods, ten of which ran along the bottom of the girder and down into the abutments. Four or possibly five of these rods were bent up about 8 or 10 ft. from the center, ran along near the top of the girder and thence downward into the abutment.

The floor system was arched longitudinally with about an 18-in. rise and reinforced with ⅝-in. round steel rods about 10 in. on centers longitudinally and transversely. The number and spacing of these bars was not very uniform, and the size or number given is only approximate. The thickness of the floor was apparently 6 to 8 in. The longitudinal rods were bent downward into the abutment and the transverse bars were bent at a 90-deg. horizontal angle about 6 in. from each end and extended into the girders. An earth filling of about 8 to 10 in. had been placed over the floor.

A man living near the bridge who helped take out the forms reported that the forms had been taken out on a Thursday, that a crack had appeared on Friday in the north girder, beginning at a point about midway between the center and the abutment and running from the bottom upward diagonally toward the center. This crack increased in width and the bridge collapsed early Sunday morning. This crack was partially discernible in the shattered pieces and apparently had been a typical tension failure crack, such as appear in beams tested to destruction. It seemed apparent to Prof. MacDonald from the examination of the structure that the failure was caused by faulty workmanship, poor grade of concrete and a poor design or a poor execution of the design rather than by any one of these causes alone.

The evident failure of the bridge was in the body of the bridge and not at the abutments. Among the facts noted which bear out this view are the following items: The concrete in the structure was brittle and in many cases small pieces could be broken off readily with the fingers. The bars were not spaced uniformly and, especially in the girders at the ends, were so close together that apparently the concrete had not come in contact with many of the bars. The gravel was obtained from a bank at the site, and while it is a good quality of bank gravel it is not uniform in size and, if used directly from the bank, a non-uniform concrete would result.

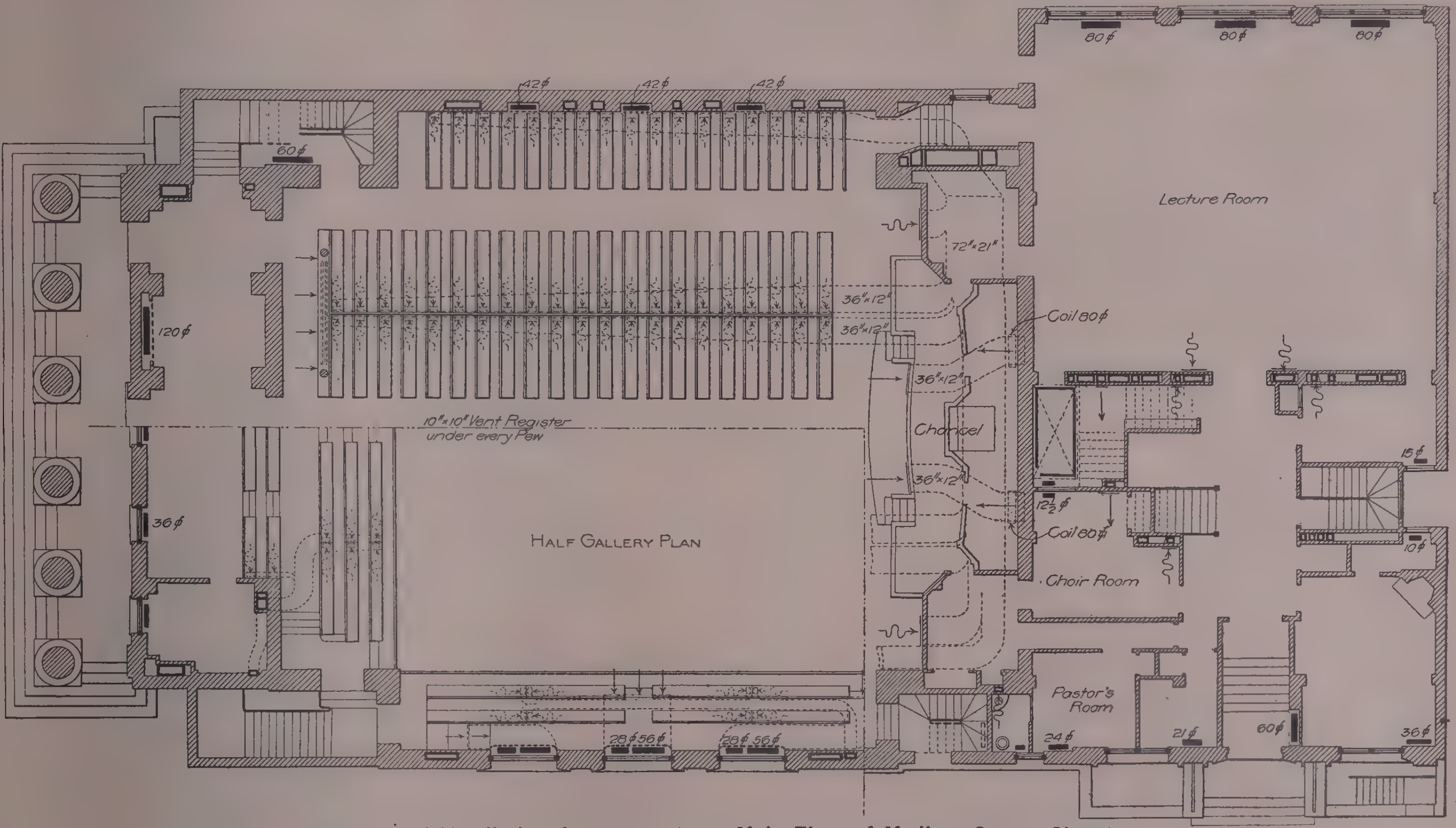
In this same county a 36-ft. reinforced concrete arch span constructed during the fall was put up in such shape that it was necessary to tear down this structure for fear of its collapsing when the forms were removed. The cause in this case was apparently a poor grade of concrete used and a further injury from frost.

The Pacific Extension of the Chicago, Milwaukee & St. Paul Ry. system will probably be completed through to the Coast in April, according to a statement given out on March 6 to the press by President A. J. Earling. The rate of construction that has been maintained during the building of this line, which has a roadbed of the best character, has probably never been equalled.

Heating and Ventilation of the Madison Square Presbyterian Church, New York.

With the recent extensions of the office building of the Metropolitan Life Insurance Co. to cover the entire block bounded by Madison and Fourth Avenues and 23rd and 24th Sts., New York City, the Madison Square Presbyterian Church, so long a landmark of the city, at the southeastern corner of Madison Ave. and 24th St., has been replaced by a new edifice on the opposite corner. In the desire of the insurance company to obtain possession of this remaining section of the block, 60 x 100 ft. in size, occupied by the church, upon which to erect its 658-ft. tower, now under construction, arrangements were made with the church authorities to secure the plot by replacing the original church by a new structure on the opposite corner of 24th St. Messrs. McKim, Mead & White were retained to draw plans subject to the approval of the church authorities.

The heating and ventilation of the new building has been looked after with unusual care and both systems involve features of marked interest. What is perhaps the most striking feature of the mechanical equipment is the absence of a steam plant for heating and power, which has been made possible by the harmonious relations existing between the church authorities and the life insurance company, that resulted in making arrangements for the supply of all the mechanical services of the church from the large modern power plant that was recently installed in the office building. This arrangement has proved a fortunate one, as it obviates the necessity of a boiler plant installation in the basement of the church with its attendant dust, dirt and heat, and, furthermore, frees the basement space for much-needed gymnasium and class-room facilities. From the office building power plant, steam is supplied at low pressure for the heating system, and at high pressure for the hot water heater of the plumbing system, while the electric power, both for electric lighting and for the operation of motors, is furnished by the New York Edison Co.



Heating and Ventilating Arrangements on Main Floor of Madison Square Church.

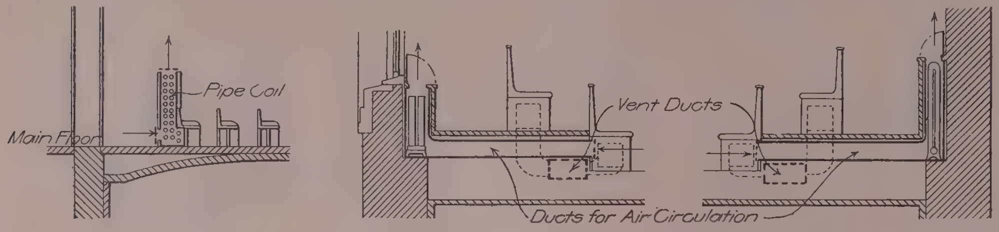
The church building consists of a 75 x 110-ft. domed edifice of an attractive architectural design, at the rear of which, on the 24th St. side, there is a 45 x 83-ft. parish house, which adjoins the 75 x 100-ft., 16-story annex building of the Metropolitan Life Insurance Co. on the northerly side of 24th St. It is constructed of a special ornamental brick, with portico on the Madison Ave. front, and finished with ornamental trimmings in terra-cotta and an attractive tile dome. The main church auditorium is 70 x 80 ft. in interior dimensions and rises, with gallery, on three sides, to an interior height of 66 ft. at the base of the dome. There is a basement under the entire site and the parish house, which is two stories and mezzanine in height, provides for a 38 x 44-ft. gymnasium in the basement, above which is a lecture room of similar size occupying the first floor, and a Sunday school room on the second floor. The remaining portions of the three floors of the parish house on the front, each 32 x 38 ft. in size, are devoted to class, study and auxiliary rooms.

Owing to the sheltered location of the church, adjoining taller buildings on the north and east sides, the exterior exposure is not excessive, which, together with the comparatively small areas of window glass installed, combines to materially simplify the problem of heating the building. The heating is provided for by direct radiation throughout the building, the fresh air supplies of the ventilation system being merely tempered to the desired interior temperatures, and some particularly interesting applications of heating surface have been made in recessed spaces and flue enclosures, and also in cornice locations for counteraction of the roof and dome exposure. The radiation was proportioned in the various parts of the building on the thermal unit basis, but special attention was given to the proportioning of the radiation where special exposures were encountered, as in the inner sides of the auditorium space, in the gallery and for counteracting the exposure of the roof areas.

The radiation is operated on the two-pipe system with the Webster vacuum system of returns and is under thermostatic control in all parts of the building. The design of the system is to heat the entire building uniformly to 70 deg. Fahr., in zero weather with steam supplied to the radiation at a pressure not exceeding 3 lb. The cast-iron radiation installed is of the Peerless type of the American Radiator Co., of the 38-in. height for the greater part, and of the Excelsior type of the same company in an indirect stack for reheating the fresh air supply to the corridor of the parish house. In the case of special circulating flues only, underneath the south gallery windows of the auditorium, are special radiators used, the limitation of space at these points requiring the use of the Bundy two-row radiators. The church is heated above the basement by a total of 2,239 sq. ft. of radiation, including the heating surface installed in entry-ways and auxiliary rooms. Of that in the main auditorium, 652 sq. ft. is installed on the main floor level, 612 sq. ft. in the galleries and 457 sq. ft. in pipe coils on the ledges of the ornamental cornice construction both surrounding the side walls and at the base of the dome.

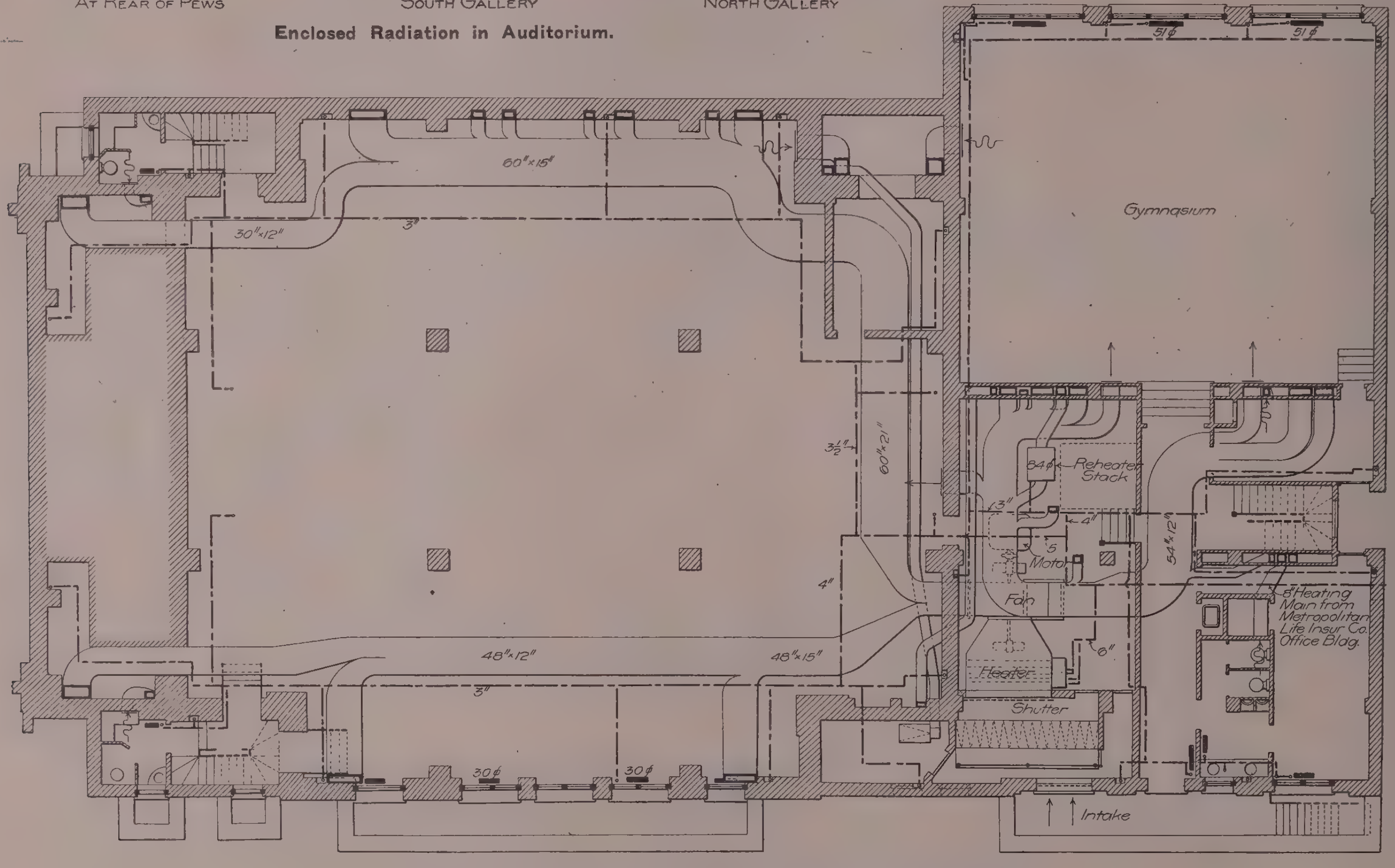
The radiation is for the greater part concealed in screened enclosures or special circulating flues, the screen enclosures occurring in the main floor vestibule and along either side wall of the auditorium at the main floor level. The latter radiators are, however, partially enclosed with inlet registers in the front casing near the base and delivery registers forming the tops of the enclosures for local circulation of air, as indicated in one of the detail sketches. The special circulating flues for both concealment or radiation and local circulation had been applied in a particularly interesting manner in several portions of the auditorium, namely, in the chancel, along the sidewalls in the gallery, and at the rear of the seating on the main floor level. The heating surface in the chancel, as well as at the rear of the two central rows of seating on the main floor, consist of pipe coils in galvanized iron enclosures insulated with magnesia blocks, which enclosures have inlet registers near the floor lines and delivery registers above them for local heat circulation. The 80-sq. ft. coils under the chancel platform have 12 x 36-in. duct connections to inlet registers in the riser front of the chancel platform and the heated air is delivered from them through chases in the wall at the rear of the chancel with delivery registers slightly above the platform level. The coils in the enclosures at the rear of the seatings are 120 sq. ft. coils of 1¼-in. pipe, arranged two pipes wide and ten pipes high, and have galvanized iron enclosures 11 in. wide inside and 60 in. high. These casings are insulated with magnesia block on the front and rear sides, and have inlet registers for their full length near the floor level on the aisle side at the rear and continuous delivery registers throughout their length on the top.

The arrangement of the flue enclosures of radiation underneath the chancel platform is duplicated at three points in each of the side galleries except that cast-iron radiators instead of pipe coils are used; in each of these cases the radiators are concealed in chases in the wall or under the window sills by removable fronts of galvanized iron with air-cell insulation covering, which enclosures all have delivery registers forming the top and connections at the base through ducts leading to inlet registers in the front portion of the gallery. In the side galleries there are but two rows of seating, the rear located on a floor level 30 in. higher than that of the front row, and advantage was taken of this arrangement to locate the intake registers in the risers of the steps leading from the lower front to the rear level, as shown in the accompanying detail sketches.



At Rear of Pews   South Gallery   North Gallery

Enclosed Radiation in Auditorium.



Arrangement of Heating and Ventilating Apparatus in Basement.

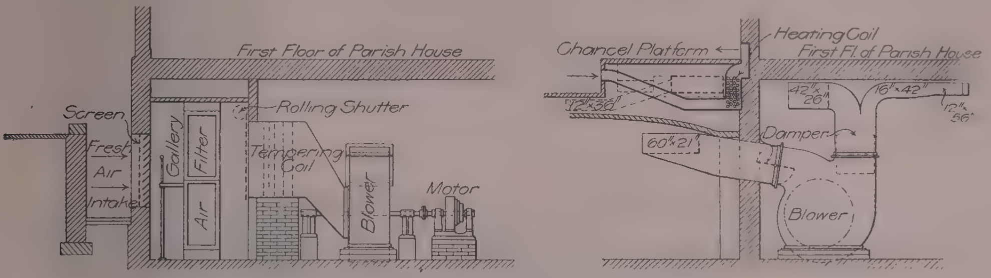
The basement underneath the auditorium, which has but a limited amount of exterior exposure, has but little radiation, consisting of four 30-sq. ft. radiators underneath elevated windows, facing sidewalk areaways on the southern side, and two radiators containing together 33 sq. ft. in toilet rooms in the front corners.

The parish house is heated by a total of 1,148 sq. ft. of radiation, of which 239 sq. ft. is in the basement, while of the remainder the second story contains the greater amount, namely, 520 sq. ft. The radiation is here distributed in the usual locations under the window sills, none of the units being screened except in the main entryway on the first floor. Limited amounts of radiation are required in the interior portion of the building for counteracting the window exposure in small light shafts that are carried down on either side for lighting and ventilation to the main floor. The location of a staircase adjoining the light shaft on the westerly side prevented the introduction of a radiator for this purpose on the main floor level and the heating requirement at this point was provided for by a special application of indirect heating from a reheater stack in the ventilation duct that supplies fresh air to this portion of the corridor space; this reheater consists of 84 sq. ft. of the Excelsior type of section enclosed in a casing of galvanized iron with insulation covering, which is suspended from the ceiling of the basement and connected into the 10 x 10-in. branch duct from the fan delivery that supplies the corridor register. The northerly portion of the parish house is devoted to large rooms, there being a 38 x 44-ft. gymnasium in the basement, a lecture room of similar size that occupies the main and mezzanine floor levels, and on the top floor above this a Sunday-school room; these rooms all have three triple windows facing the areaway at the rear, which exposure is counteracted on each of the three floors by three radiators which are of 51-sq. ft. units in the basement, 80 sq. ft. on the main floor, and 100 sq. ft. on the upper floor.

Steam is supplied to the radiation in the church and parish house by an 8-in. pipe connection that is extended into the basement from the low-pressure heating mains of the office building system, which, together with the high-pressure steam and return lines, enter the basement under the parish house at a point about 20 ft. to the rear of the front wall. This main divides into two 6-in. branches, one supplying the fan tempering coil of the ventilating system, and the other the riser lines to the direct radiation on the upper floors. The latter branch divides into a 4-in. line supplying the parish house and a 5-in. main to the church, both of which sub-divide to supply branches leading to all points where riser lines are located. There are 13 riser lines installed which supply the radiation in the church, and six for the parish house, which lines range from 1¼ to 2½-in. pipes. The riser lines are in every case run in chases in the wall construction for entire concealment, and all branch connections to radiators are run under the floor construction, the insulation coverings being there protected by iron sleeves. The high-pressure service in the building consists merely of a 1½-in. line from the office building power plant, which supplies steam at reduced pressure to a hot water heater tank for the plumbing service.

Condensation is returned from the radiation by a Webster vacuum system which is installed to form a part of the return system of the office building power plant, each riser line and supply connection to direct or indirect radiation being paralleled by a return riser or connection which delivers in the basement into a return gathering main. Connections are made to the radiators and coils through the usual Webster thermostatic valves, none of which are installed smaller than 1 in., while all units above 72 sq. ft. of radiation have 1¼-in. return connections. The return gathering main is carried through a portion of the auditorium basement and across the basement under the parish houses in trenches, being graded for return by gravity, and the line leaves the building as a 4-in. return main.

Temperature regulation is provided for on the Johnson system throughout the greater part of the building, there being in all 40 heat sources controlled by 22 thermostats. In the basement there is a cold air and a hot air thermostat controlling different sections of the fan-system tempering coil and a hot water thermostat controlling the plumbing service heater. The temperature is regulated in the church auditorium by five thermostats on the main floor level, which control six radiators and four coils, and two in the gallery controlling six radiators, there being in addition one thermostat in the main church entrance, three in the gallery stairways, and two in the organ chamber for the local control of radiation. Thermostatic control is provided in the parish house only in the lecture room, on the main floor and in the Sunday-school room and class-rooms on the top floor. A feature of the temperature control system is the provision of an outside thermostat to control a small part of the heating surface in the large windows above the gallery on the south side of the auditorium, which open these sections whenever the outside temperature drops below a certain degree in order to secure continuous heating effect from these surfaces when needed. Pneumatic valves as used in the temperature regulation system are also applied to steam and return ends of all skylight coils with connections from them to three-way hand valves located in convenient positions below for hand control of these heating surfaces. For the above equipment the standard Johnson apparatus has been used throughout, the compressed air supply for the operation of which is supplied from the office building power plant.

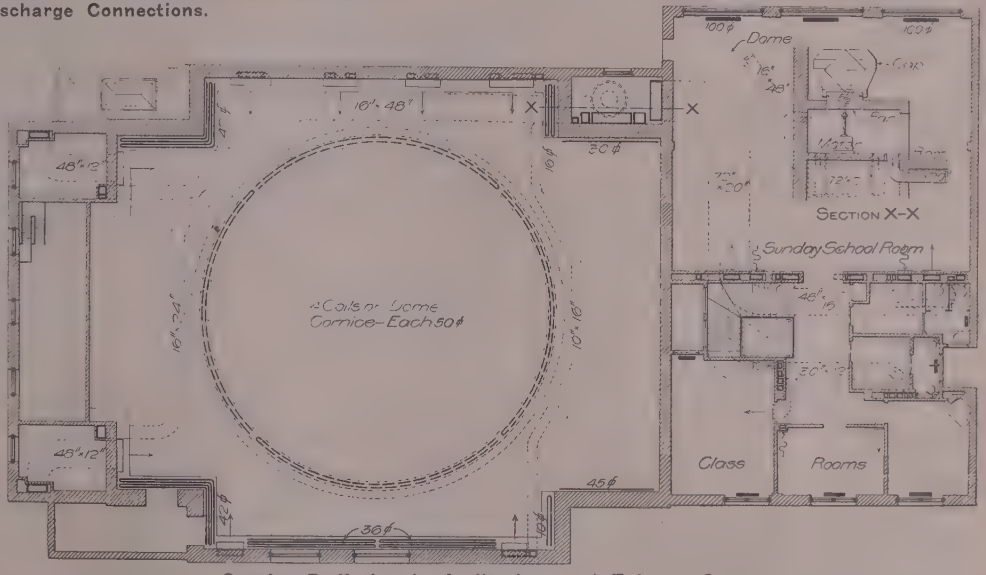


Basement Fan and Discharge Connections.

Ventilation.—Thorough ventilation is provided for in both the church building and the parish house, including both fresh air supply and exhaust which, owing to the independence of the heating and ventilation in this building are applied on the downward plenum system. An interesting feature of the ventilating system is the installation of a single equipment each for both fresh air supply and exhaust ventilation, with provisions for the operation of either equipment on either the auditorium or the parish house, which arrangement was rendered possible by the intermittent occupancy of the two divisions of the building and in addition, the fact that both are seldom, if ever, fully occupied at the same time. The installation of mechanical equipment was materially simplified by an arrangement of the fresh air intake through a sidewalk areaway window at the basement level, which was permitted by the use of air filters in the fan intake for cleansing the air supply. This enabled the fan to be located in a convenient position in the basement, both in reference to the intake and heating connections for the tempering coil and for the delivery duct lines to both the auditorium and the parish house.

The fresh air supply system consists of a 6-ft. centrifugal motor-driven fan, located in the front portion of the basement underneath the parish house, in close proximity to the division wall separating this portion from the church building proper, and to the intake connection to the filter chamber and with two separate lines of delivery ducts, one leading to the parish house distribution and the other to the church auditorium. The blower is a full-housed steel-plate centrifugal fan with a top vertical and a top horizontal discharge outlets in duplicate for independent connections, each 42 in. square, to the parish house and church auditorium systems, and has a wheel with curved blade 6 ft. in diameter by 3½ ft. wide. The wheel is driven by a 6-h.-p. C. & C. direct-current motor, which is fitted for speed regulation by field control from 110 to 170 r.p.m., at which maximum speed the fan has a delivery capacity of 20,000 cu. ft. per minute. The motor is direct connected to the fan shaft by a flexible flange coupling and operates on the 110-volt power service mains that are brought into the building.

In the fan intake connection from the filter chamber, which adjoins the intake window at the front, there is a tempering coil consisting of four two-row and one four-row sections, each 6 ft. high by 8 ft. wide, which are of the standard heater coil construction of the B. F. Sturtevant Co., with separate cast-iron headers on the steam and return ends. The coils are of 1-in. pipe presenting 1,160 sq. ft. of heating surface and, like the direct radiation in the building, are fitted for automatic temperature control from thermostats and motor valves on the Johnson system, one of which thermostats is located in the cold air inlet and controls the two outside sections of the coil and the other is in the tempered air duct and controls the two inside sections of the coil.



Cornice Radiation in Auditorium and Exhaust System.

The air filters are of the cheese-cloth type, with the filtering medium on wooden frames mounted in zig-zag arrangement on galvanized iron framework. The filter is located in a 8½ x 19-ft. chamber between the tempering coil and the intake window, and consits of 60 frames, 3 x 6-ft. in size, which are mounted in two tiers in the galvanized iron framework, with a galvanized iron platform for access to the upper tier. The wooden frames are covered with wire netting to serve as backing for the filtering medium, and the 60 frames present a total effective area of the filtering medium of approximately 700 sq. ft. This area is sufficient to reduce the filtering velocity when the fan is operating at its maximum capacity of 20,000 cu. ft. per minute to a safe figure slightly less than 30 ft. per minute. There is also provided for the filter equipment a filter frame cleaning hopper, on which the frames may be placed with the inlet sides down and beaten, this hopper connecting on the lower side with the vent fan on the roof for removal of the dust and dirt by exhaust. The air is admitted to the filter chamber through the 72 x 80-in. outside window, which is fitted with a wire screen of 1-in. mesh and louvres of 30-oz. copper, and for closing the chamber to the outside air in case the system is shut down, there is provided a Kinnear rolling shutter on the inside.

Fresh air delivery to the church auditorium is made through openings above the cornice finish in the upper side walls, which are 37 ft. above the main floor level, from which point the fresh air diffuses downward, displacing the foul air into the exhaust openings at the gallery and main floor level. There are four of the fresh air supply registers arranged at the northerly wall of the auditorium, two at the southerly side above the side windows and two in the westerly or front corners. The eight supply registers are installed in three different sizes, namely, 16 x 60 in. for those in the west wall and two in the northerly wall, 16 x 72 in. for the other two in the northerly wall, and 16 x 48 in. for those in the south wall. They are supplied by flues rising in chases in the wall construction, direct from the distributing ducts in the basement, which flues are so proportioned as to distribute the outflow evenly between the eight registers. As these registers are located at a considerable distance above the audience and direct the outflow upward toward the dome, the comparatively high delivery velocities of 400 ft. per minute, as provided for with the fan operated to full capacity, are permissible. The vertical flues are designed for velocities of flow averaging 700 ft. per minute, while in the distributing duct work on the ceiling of the basement underneath the auditorium, which consists of two lines of shallow rectangular main ducts that follow either wall line of the building, the flow velocity ranges between about 1,600 ft. per minute at the fan connection and 1,200 ft. per minute in the main duct line. The capacity of supply available from the fan when operated to its maximum of 20,000 cu. ft. per minute, provides the required supply of 30 cu. ft. per capita for an audience of nearly 700, which approximates very closely the maximum audience that the auditorium will accommodate; the seating capacity of the auditorium is nearly 800, of which 200 are in the gallery and about 600 on the main floor.

The fresh air supply to the parish house is, as above stated, provided for by the duplicate delivery outlet from the fan, the two outlets being dampered so that the air supply may be delivered exclusively to the church auditorium or to the parish house, or divided between the two in any proportion at will. The air supplied to the parish house is distributed almost entirely through flues that rise through the furred partition wall that is carried up through the center of the building to separate the larger rooms, including the lecture room and Sunday-school room, from the smaller rooms at the front. The arrangement of these wall flues and their connections to the distributing ducts from the fan are well shown in the basement plan. There are but three fresh air supply outlets in the basement, one of which is a register supplying the church basement under the main auditorium, and the other two, the gymnasium at the rear. There are on the upper floors, however, connections to practically every room, except certain of the smaller private rooms and offices that have front window exposure. The gymnasium in the basement has two 20 x 24-in. register supplies, in the lecture room on the main floor there are three 24 x 24-in. registers and the Sunday-School room on the upper floor, two 30 x 24-in. register supplies. While the duct work of the parish house system is designed for handling the maximum output of the fan which would provide from six to eight changes of air per hour well distributed throughout the entire parish house, this rate of ventilation will be rarely required and provision is made for a lower rate of ventilation by the speed range in the fan motor which enables the fan to be operated at as low a capacity as two-thirds of its rating.

The exhaust ventilation from both the church auditorium and the parish house is effected by a disk exhaust fan located in a pent house enclosure above the roof of the church building at the rear corner. This exhaust fan is a Blackman disk fan, 5 ft. in diameter, which is mounted on a vertical shaft in the roof of the pent house at the base of the discharge hood with direct connection to a vertical shaft electric motor below it. The latter is a 4-h.-p. C. & C. electric motor, and is designed to operate at speeds ranging from 150 to 225 r.p.m., at which latter speed the exhaust fan has a maximum capacity of 20,000 cu. ft. per minute. This fan is operated on the power service main in the building, and is controlled from a speed-regulating starting box located in the pent house. The fan draws directly from the pent house enclosure, which is 7 x 13½ ft. in plan and 6½ ft. high inside, and serves as an exhaust chamber, the exhaust flues from both the church auditorium and the parish house opening directly into it. The discharge cap is a large galvanized iron weather-proof hood, which is mounted directly on the fan ring enclosed in the roof construction.

The exhaust connections are, like those for fresh air supply, proportioned for about equal capacity of exhaust from both the church auditorium and the parish house, and a feature of this portion of the ventilating system is the provision, due to the inaccessible location of the fan pent house on the roof, of pneumatically operated dampers in each of the exhaust duct connections into the pent house with control connections in the basement by means of which the exhaust may be thrown on to either system or divided between the two. The exhaust from the church auditorium is affected entirely through register openings in the floors, the arrangement of these registers being, as shown in the auditorium plan, underneath the pews at the inner ends on both the main floor and in the gallery. These exhaust registers in the floor are all 10 x 10-in. register faces which have 5 x 10-in. duct connections to large exhaust gathering flues underneath the floor, the proportions being for rates of inflow not to exceed 160 ft. per minute, which rate is, however, increased in the duct connections to about twice that value. There are 150 of these registers for the auditorium exhaust, of which 118 are on the main floor and 32 in the gallery, under pews, and they all connect through 5 x 10-in. branch ducts into the main gathering flues, which are concealed under the floor construction. The auditorium has exhaust connections, in addition to the above mentioned floor registers through two 12 x 36-in. registers in the lower front walls on either side of the chancel near the floor line, which together withdraw about 4,000 cu. ft. per minute at rates of inflow of about 700 ft. per minute. The gathering duct connections to these exhaust registers and those under the pews on the main floor level are all carried forward under the floor construction to a trunk duct that leads crosswise under the chancel to a 21 x 72-in. flue furred into the wall construction at the rear corner. The gathering ducts under the gallery floors are, owing to their scattered arrangement, connected to the pent house exhaust chamber through separate flues for either side gallery and two for the rear gallery which are carried up and over the ceiling finish on either side of the dome to the exhaust fan. All of this exhaust duct work is proportioned for velocities of flow when the fan is operated to its maximum capacity of about 1,200 ft. per minute.

The exhaust ventilation of the parish house is operated by a 20 x 72-in. duct connection from the fan house above the second floor ceiling construction to wall flues that serve the various rooms in the upper portion, and two independent exhaust flues, one 21 in. square, that draws from the gymnasium in the basement, and the other, 18 x 21 in., which exhausts from the basement space under the main auditorium of the church. The exhaust registers in the various rooms are located in the side walls near the floor lines, and are similar in general arrangement to those for fresh air supply, except that they are generally from 20 to 25 per cent. smaller in total area of opening than the air supply openings. The wall flues serving these exhaust registers are arranged in the same furred partition through the center of the parish house in which the air supply ducts are located with the exception of a few ducts serving rooms on the mezzanine and second floor at the front side, which are installed in special furred partitions adjoining the corridor. These wall flues join above the second floor ceiling construction into two branch ducts, which together form the 20 x 72-in. main connection to the fan in the pent house. The design of the system in the parish house is such that with the exhaust fan operating to its full capacity, the rate of inflow does not greatly exceed 300 ft. per minute.

The heating and ventilation systems of the church building and parish house were designed by Mr. Alfred R. Wolff, consulting engineer, New York, by whom the designs of the power plant in the office building of the Metropolitan Life Insurance Co., from which the mechanical equipment of this building is operated, were made. The heating and ventilating equipment were installed by the Wells & Newton Co. Messrs. McKim, Mead & White, architects, New York, were the architects for the church and parish house.

A Pumping-Engine Test was made during the last fiscal year by Supt. W. A. McFarland, of the Washington, D. C., Water Department, which is interesting as showing a better performance, 166,500,000 ft.-lb. per 1000 lb. of dry steam, than was attained with the same engine, an Allis-Chalmers, during its official duty trial a year before.

Sewage Disposal at Birmingham, England.

The city of Birmingham, England, has nearly completed, under the direction of Mr. J. D. Watson, a large sewage disposal system, which was recently visited by Supt. D. E. McComb, of the Washington, D. C., Sewer Department. In his annual report for last year he gives the following description of the works:

"The sewage is first discharged into six open tanks; about 30 ft. from the receiving end of each tank is a transverse division wall over which the sewage flows into the second section of the tank. The grit and other heavy materials are retained in the first section and are removed about once a week, one tank being cleaned each working day. The materials removed are used to fill up low portions of the old sewage farm. The removal of sludge and grit at the short intervals noted causes little odor and consequently minimizes the nuisance usually incident to that important detail of the operation of sewage plants. The second portions of the six tanks are used as primary septic tanks; the sewage from these tanks passes over a weir into a channel in which it flows to the secondary septic tanks. These tanks were formerly used for sedimentation of sewage before it was applied to the land.

"From the septic tanks the sewage is conveyed in a closed conduit to a reservoir about 3 miles distant, thence to six tanks constructed on the Dortmund principle wherein sludge is deposited, which is used to fill adjacent low ground. From these tanks the sewage is conveyed to the filters.

"The filters are each about 1.5 acres in area and 6 ft. deep. A concrete floor about 6 in. thick is first laid, the surface having a slight inclination toward a collecting gutter laid along one of the longer sides of the rectangle and just outside the inclosing wall. Upon the concrete floor a second floor of drainage tile is laid. Contiguous tiles are laid about an inch apart, a lug being cast on each section to insure against too close contact. These tiles provide semi-circular openings above the floor about 4½ x 9 in., 15 in. apart, which discharge into the collecting gutter. The material of the filter, consisting of broken stone, pottery waste or other hard material, is then placed upon the tile floor. The lower layer is of 2½ in. ballast and the material of the bed grades up to the ⅜-in. ballast of the top layer. The material used is well screened and graded. The sides of the beds are protected by dry rubble walls. The sewage is distributed by a grill of piping laid upon the top layer of stone with sprinkling nozzles, so placed that they divide the beds into 8-ft. squares. The pipes have openings midway between the sprinklers, and the positions of the sprinklers are changed when the appearance of the surface of the bed indicates that such is desirable.

"The sewage flows from the filters to tanks where the flocculent suspended matter is deposited. From these tanks the effluent flows into the river Tame.

"The dry solid matter removed by the Dortmund tanks amounts to 1.027 tons per million gallons of septic sewage. The results attained indicate that each acre of sprinkling filter bed will efficiently purify 750,000 gal. of Birmingham sewage, the effluent being non-putrescible. The sewage received amounts to the rate of 60 gal. per capita per day of contributing population; the water supply rate is 35 gal. per capita. Upon the basis of population, each acre of sprinkling filter bed will purify sewage from 12,500 persons."

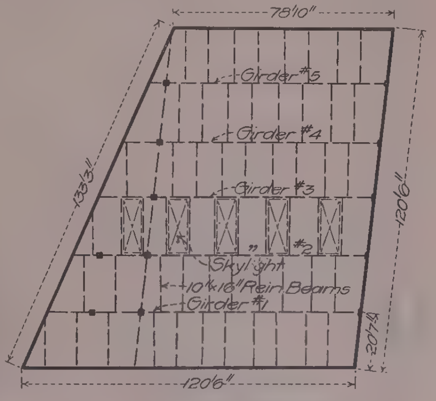
The Transverse Crowning of streets in Frankfort, Germany, is one-fortieth of the width for macadam, one-fiftieth for ordinary block paving with ungrouted joints, one-sixtieth for the better class of blocks with grouted joints, one-eightieth for wood paving and one one-hundredth for asphalt paving.

The Foundry Building of Williams, White & Co., Moline, Ill.

The reinforced concrete one-story foundry building of Messrs. Williams, White & Co., Moline, Ill., occupies an irregular area 133 ft. 3 in. x 120 ft. 6 in. in extreme dimensions, as shown in accompanying illustrations. Practically the entire enclosed space is unobstructed by interior columns, there being only seven such columns in all and these being arranged along the longest side of the building as shown. The flat roof consists of a 4-in. slab of concrete and about 40 per cent. of its area is taken up by skylights, each of which is about 7x18 ft.

Over the unobstructed area or craneway, which is about 78 x 123 ft., the roof is carried by the end walls, and by five very large girders with a clear span of 74 ft. 8 in. Between these girders, which are placed approximately 20 ft. on centers, extend 10x16 in. beams placed along both sides of every skylight. The main roof girders are 78 in. deep, including the 4-in. roof slab, and 16 and 28 in. wide at the bottom and top, respectively, the increased width in the upper part being necessary to provide sufficient compression area.

The Kahn system of reinforcement was used throughout the structure. On account of the span of the main girders and the fact that it was impossible to make them continuous, it was considered necessary that the diagonal or shear members be rigidly attached to the main horizontal reinforcement. One of the special features of the Kahn system was used therefore—that is, rigid attachment was secured by riveting angles and flats to obtain the desired reinforcement.



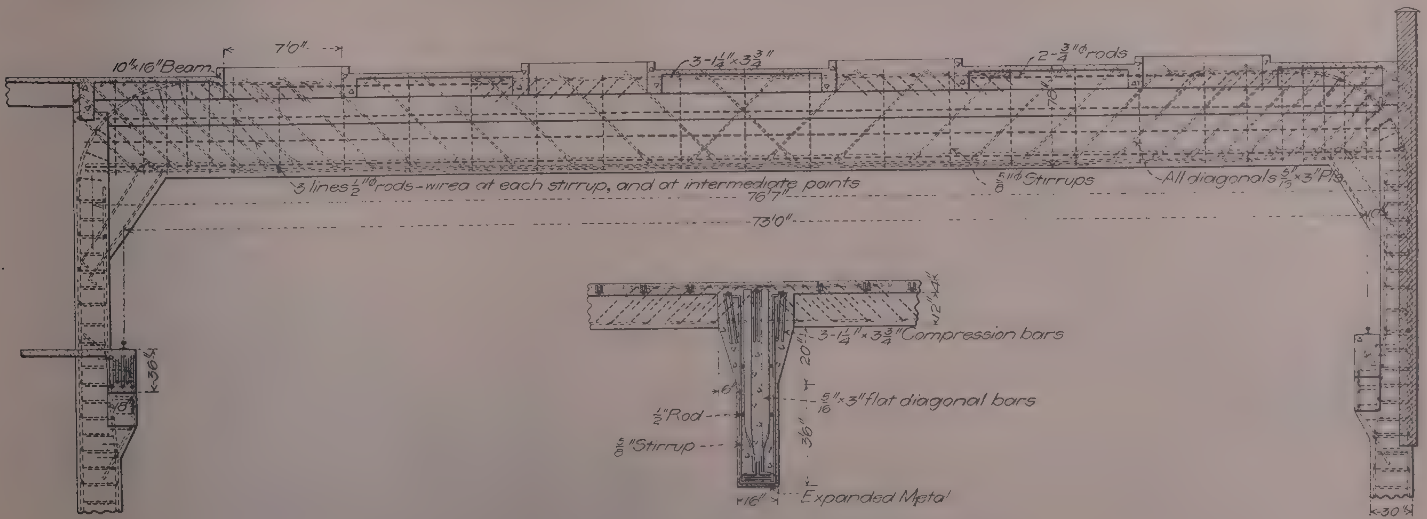
Plan of Foundry Building.

The crane, which was supplied by the Niles-Bement-Pond Co., has a clear span of 73 ft., center to center of rails, and a nominal capacity of 15 tons and has been tested in place with a load of 30 tons. The rails are carried on 18 x 36-in. girders reinforced with Kahn bars. These girders rest on brackets formed on the columns as shown on the drawings.

Construction work on the building was started in 1906 and after some delay during cold winter weather, when work was suspended, the building was finished early in the Spring of 1907. When the forms were removed from the main roof girders, level readings taken on consecutive girders indicated the following deflections: No. 1, 1/16 in.; No. 2, 3/16 in.; No. 3, 3/16 in.; No. 4, 5/16 in.; No. 5, ⅜ in. The maximum deflection was accordingly 1/2400 of the span. Owing to a breakdown of the concreting machinery about one month's time elapsed between the concreting of girders 1, 2, 3, and girders 4 and 5. This, together with the fact that girders 1, 2 and 3 are continuous at one end, explains the variations in the deflections. The building has now been in use about 8 months and is giving entire satisfaction.

The building was constructed by the Tri-City Construction Co., of Davenport, Ia., in accordance with plans prepared by the Trussed Concrete Steel Co., Detroit, Mich.

Interior of Foundry Showing 74-Ft. 8-In. Roof Girders.


10"x16" Beam
7'0"
3-1¼"x3¾"
2-¾"φ rods
3 lines ½"φ rods-wired at each stirrup, and at intermediate points
⅝"φ Stirrups
All diagonals 5/16"x3" Pls.
76'7"
73'0"
78"
36"
18"
12"
4"
3-1¼"x3¾" Compression bars
20"
6"
5/16"x3" flat diagonal bars
½" Rod
⅝" Stirrup
36"
16"
Expanded Metal
30"

Sections of Roof Girders in the Williams, White & Co. Foundry, Moline, Ill.

THE METROPOLITAN DISTRICT RAILWAY, of London, has been worked by electric traction for a longer period than the Metropolitan Railway, mentioned on Feb. 29. The total mileage of the last six months of 1907 was 1,679,800 train-miles, as compared with 1,624,300 train-miles in the last half of 1906. The average cost of electric train working during the second half of 1907 was 24.8 cents per train-mile, as compared with 24.5 cents in the corresponding six months of 1906. The additional expense in 1907 is partly explained by the higher price paid for coal. These figures of cost include the charges for current, wages of train crews and the expenses for car cleaning, terminals and supplies. The company carried 55,100,000 passengers in 1906 and 51,200,000 passengers in 1907. Although there was a falling off, therefore, in the number of passengers, the revenue increased from £403,300 in 1906 to £406,900 in 1907. The company's revenues in 1907 were somewhat under those of 1898, a fact that is significant of the growing importance of other methods of rapid transit in London, not only the new tube lines, but also the street railways.

The Transmission Towers of the Great Western Power Co.

The Great Western Power Co., of California, has adopted the Milliken tower for use in carrying its high-voltage power transmission line. The power is transmitted on two circuits of three wires each, carrying a current of 100,000 volts. In view of this high voltage and the consequent danger, great care was exercised in selecting the particular class of towers to be adopted.

The tower is designed with three crossarms, it being intended to carry a feed wire on the outer end of each crossarm by suspended insulation. The top of the tower is arranged to take a guard wire. The towers are intended to be used about 750 ft. apart.

The photograph shows a view of the tower parallel with the crossarm. The bottom of lowest crossarm is 51 ft. 2 in. above the ground, and the second crossarm is 10 ft. above the first, and the third crossarm is 10 ft. above the second. The extreme top of the tower carrying a guard wire is 5 ft. 1 in. above the bottom of the highest crossarm. The feed wires are 17 ft. 1 in. from each other in a horizontal plane for the two upper crossarms, and 18 ft. 1 in. for the lowest crossarm; thus making all feed wires 6 ft. 5 in. from the nearest part of the tower proper measured in a horizontal direction.

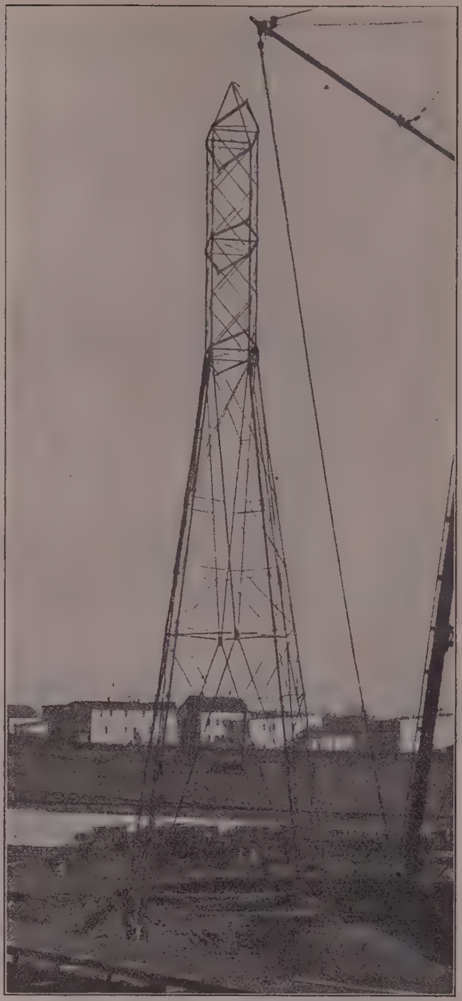
The bottom of the tower at the ground level occupies a base 17 ft. square. The stub ends, the portion in the ground, are separate pieces of steel and are of such length as to allow 6 ft. for bedding in the ground.

These towers are constructed entirely of structural steel shapes and are designed to follow the theoretical stresses and produce a tower of given strength and stiffness, with a minimum amount of material. There are a great many duplicate pieces; thus making it a simple matter for the purchaser to put the same together in the field. Very complete and careful tests of their strength were made before their regular manufacture was started. The tower was erected in a vertical position on an immovable concrete foundation. The strains were applied by means of weights hanging from a fixed structure, and the amount of load and deflection was easily determined.

The tower was designed to stand the following tests: When tested in a vertical position, on an immovable foundation, and with a proper margin of safety, a simultaneous horizontal side pull of 1,000 lb. at the top and 2,500 lb. at each of the three crossarms, or in other words, a total strain of 8,500 lb., the crossarms were to support a suspended weight of 1,000 lb. at their extreme end, and any one of the crossarms to carry at one of these ends a horizontal pull along the line of 3,000 lb.

The receivers of Milliken Bros. (inc.), 11 Broadway, New York City, are manufacturing these poles at Milliken, Staten Island, N. Y., where special arrangements have been made in the bridge and structural shops for getting out this particular class of structural work. As all of this material (except bolts and nuts) is galvanized by the hot process before shipment, and after all the shop work has been done, there has been added to the Milliken plant a large galvanizing department for doing this particular work. In fact, it is unique in that it has probably the largest hot galvanizing bath ever constructed. This is capable of taking pieces somewhat over 30 ft. in length at a single dipping, which is a decided improvement over the old-fashioned method of dipping long pieces one end at a time.

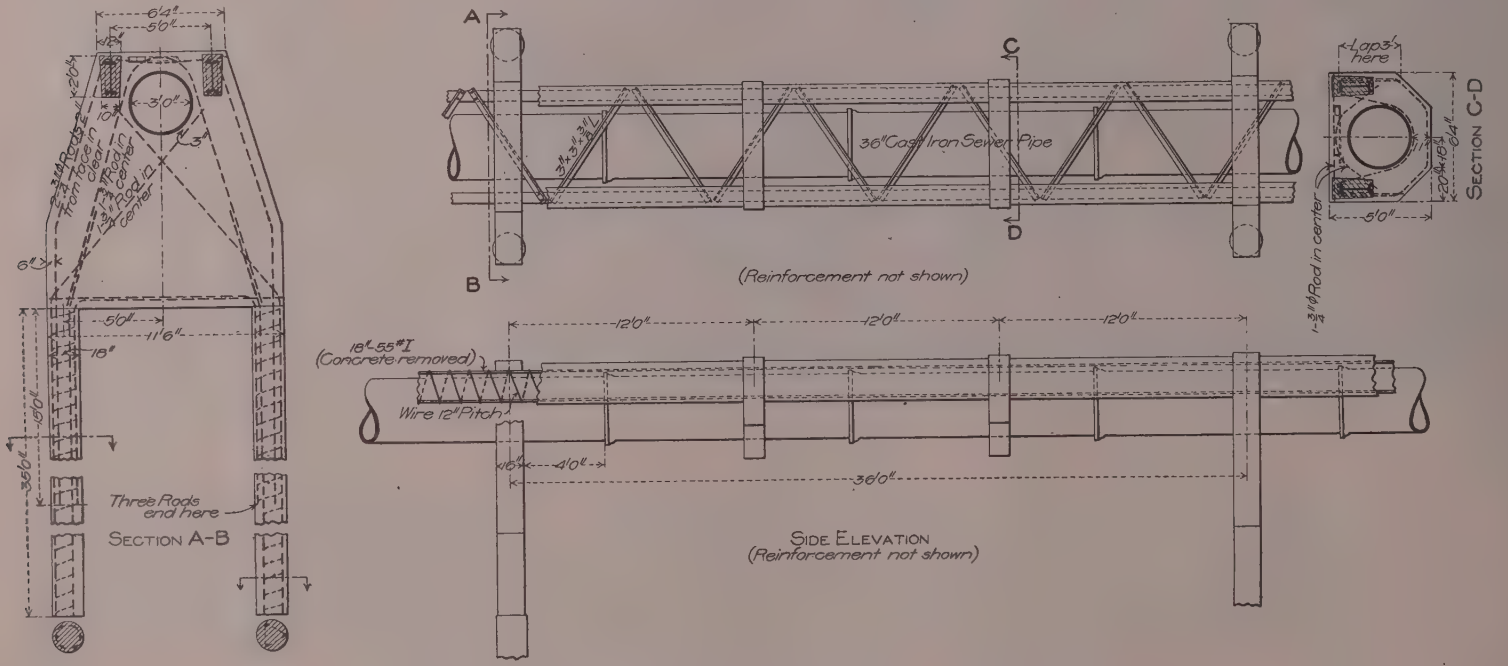
These towers are all put together with bolts, and to reduce freight charges are shipped knocked down. They can be put together on the ground, and then tipped up vertically as they are stiff enough in themselves to stand being erected in one piece, thus obviating the necessity of erecting them piecemeal from the ground up.



Tower for Transmission Line.

London Electric Supply Confusion

Another attempt is being made to unravel the confusion existing in the electric supply situation in the London district, which is generally acknowledged to be a source of great, needless expense to those using current. Over seventy distinct authorities in the district now sell current; some of them are private companies engaged in competitive business and others are public boards having a monopoly within their territory. The current is furnished from about 65 stations, many of them containing only antiquated units of small capacity, as is evident from the fact that the average capacity of the units throughout the district is under 400 kw. The current is supplied on nearly 20 different systems of frequency and voltage and the charges for it range from 1½ to 20 cents per kilowatt-hour. The first attempt to avoid the losses incident to such a wasteful condition was made nearly 20 years ago by Ferranti, but failed on account of technical defects which made the distribution of current over a large area impracticable at that time by the methods he tried. Since then some of the companies concentrated their plants in large stations, but none attempted to distribute current outside its territory. Now eight of them, having four-fifths of all the capital invested in central stations in the district, have asked Parliament to permit them to sell current in bulk to each other and to other authorities for distribution to consumers.



Details of Reinforced Concrete Pipe Trestle Across the Los Angeles River.

A Reinforced-Concrete Sewer Pipe Trestle.

A reinforced-concrete pipe trestle has recently been built in Los Angeles, California, to carry an intercepting sewer across the Los Angeles River. The latter flows from the north to the south through the eastern part of the city, practically all of the business section and most of the residence districts being to the west of it. The storm-water run-off is carried directly to the river and to various other watercourses, while the domestic sewage is diverted into a long outfall sewer leading to the Pacific Ocean, some 15 miles distant. The construction of this outfall was fully described in The Engineering Record of Jan. 25, 1908. Although most of the city is to the west of the river, the territory east of the latter contains a large population and is served by an intercepting sewer, which extends across the river to a connection leading to the outfall.

The river crossing is made in a 36-in. cast iron pipe, that was laid across the bed of the stream on a timber trestle in 1893, the surface of the sand being 3½ ft. above the top of the pipe at that time. The nature of the river is such that this crossing was maintained with difficulty. The river is in a narrow geological valley that has been filled with material washed down from the mountains and hills farther upstream until a deposit of sand and gravel of great depth makes up the bed of the stream. The flow of the river is remarkably uniform throughout the year, amounting to a small stream only except for occasional floods of short duration in the rainy season, and being entirely dry for several months each year at the crossing. On account of the nature of the stream bed, no advantage could be gained by changing the location of the crossing. At the same time, any possibility of placing the pipe under the surface of the stream bed was precluded, as the channel of the stream varies greatly, due to the shifting sand bed. A large amount of gravel and sand is also removed from the channel continuously for various purposes, with the result that the level of the sand surface has been lowered 14 ft. in fifteen years.

Completed Trestle Across Los Angeles River.

The official width of the river at the crossing is 300 ft., the banks being confined on both sides. The 36-in. pipe was originally carried by timber pile bents, spaced one to each 12-ft length of pipe. As the original bents had practically failed, they were replaced in 1903 by bents of the same type. Between 1893 and 1903 the sand surface was lowered 6½ ft., leaving the sewer exposed. The new bents each had three pile posts, one on the upstream and two on the downstream side of the pipe, with two cross timbers above and two below the pipe. Heavy floods in the last few years had pushed these bents out of line badly and some of the timbers had decayed, so the decision was made about a year ago to replace them by the permanent reinforced-concrete trestle.

This trestle consists of two-post reinforced-concrete pier bents, with two heavy beams between the bents, one on each side of the 36-in. cast iron pipe. The arrangement of the trestle and the details of one bent are shown in accompanying illustrations. The two posts of each bent are capped by a reinforced-concrete pier, the transverse center lines of these piers being 36 ft. apart. This spacing brings one pier 7 ft. 4 in. from one end of every third 12-ft. length of the pipe. The two intervening 12-ft. lengths of pipe are each carried independently by a reinforced-concrete rib built between the pair of beams extending from pier to pier of the bents. A series of unobstructed waterways, each 34 ft. 8 in. wide and of the same height as existed with the original structure is thus obtained.

The two posts of each bent are 18 in. in diameter, 35 ft. long and are spaced 10 ft. apart on centers, with their tops from 2½ to 10 ft. below the sand line of the stream bed. The reinforced-concrete pier cap on the pair of posts of each bent is 16 in. thick and 12½ ft. high, the top of the 36-in. pipe being imbedded 11 in. below the top of the pier.

The posts are reinforced from the bottom to the top as spirally-hooped columns. Six ¾-in. round rods, placed at the corners of a hexagon and wrapped spirally with 3/16-in. black wire, extend to a depth of 15 ft. Three of these rods are continued to the bottom of the posts and are placed at the corners of a triangle, the spiral wrapping wire being continuous from the bottom to the top of the post. In all of the posts the rods are 2⅜ in. from the surface of the concrete. The rods all extend up into the pier cap, one of the rods in each post being bent horizontally across the bottom of the pier to the top of the other post. The remaining rods are distributed through the pier in such manner as to tie the latter to the posts thoroughly, to anchor the 36-in. pipe and to bond into the pier the beams between the bents.

The grade of the 36-in. pipe could not be disturbed, owing to the elevation of connections at both ends of the crossing. On the other hand, all of the waterway that could be obtained was essentially necessary to provide for flood flows. These conditions required the lower flanges of the two beams carrying the pipe between the bents to be placed 2 in. above the horizontal center line of the pipe, in order to permit transverse diagonal bracing to be placed over the pipe. This arrangement of the beams required the two 12-ft. lengths of pipe intermediate between the bents to be suspended rather than supported.

Each of the two beams consists of an 18-in. 55-lb. steel I-beam wrapped spirally with 3/16-in. iron wire, and surrounded with concrete. The steel beams are in alternate lengths, which are spliced together to make them continuous. Before the concrete was poured around these beams they were braced laterally by 3 x 3 x ⅜-in. angle lacing bars placed over the top of the pipe.

The concrete rib placed around each of the two 12-ft. lengths of pipe between the bents is 12 in. thick and is thoroughly tied to the longitudinal beams by reinforcing rods, placed as shown in one of the illustrations. The lower flange of these ribs is 11 in. below the bottom of the pipe and contains two pairs of ¾-in. rods, placed so as to transmit the entire weight of the pipe to the beams. The latter are also tied together at the top of the rib by two ¾-in. rods, thus providing additional latteral bracing between the beams. To provide for inequality of expansion the concrete in the bents and ribs was separated from the pipe by two layers of felt.

The bents and ribs of the trestle were spaced alternately with the old pile bents, in order that the new structure could be built without interfering with the old one. This arrangement also permitted the concrete in the new trestle to set before the load was brought on it. The construction was undertaken last summer when the surface flow of the river had disappeared entirely and the ground-water level had dropped to a depth of 20 ft. below the surface. A well, lined with No. 14 double casing, was sunk for each post of the trestle bents. The casings were nearly watertight, but after the ground-water level was reached some water came up through the bottom. To avoid placing concrete in the water, the bottom of each well was sealed with concrete and after the latter had set, the water was pumped out, so the concrete for the balance of the posts could be built in the dry.

The removal of sand from the channel has resulted in the piers of 10 bridges which cross the river in the city being rapidly endangered, and if this sand removal is continued these piers will have to be underpinned. Ultimately, however, the removal of sand will have to be restricted, unless a protracted flood brings down an immense quantity of material from above, which is an improbable contingency. The posts of the trestle were, nevertheless, made of such length that long before the structure might be threatened by the further lowering of the channel, the sand removal will have been restricted.

The trestle was designed and built under the direction of Mr. Homer Hamlin, city engineer of Los Angeles. Mr. H. G. Parker was engineer in immediate charge of the design and construction.

The Benardos Electric Welding Process is being considerably used in the Pittsburg district, particularly for repairing steel castings, as it is simple and easily operated, and requires no elaborate equipment. It consists of drawing an electric arc at 50 to 60 volts between a carbon electrode and the metal to be welded, until the metal begins to melt and boil, molds being used to confine the molten material. The process is also effective in filling holes or building up raised portions on castings. In either of these operations the casting is first thoroughly heated by the arc and then iron rods or scraps of boiler plates are thrown in, molds retaining the molten metal in raised work. Direct current is used at 100 to 125 volts and the current required is high, ranging from 500 to 1000 amperes for ordinary work.

Operating Results at the Harrisburg Filters

The mechanical filtration plant of the Harrisburg, Pa., water-works, built from the plans and under the supervision of Mr. James H. Fuertes, consulting engineer, New York, was described in this journal on March 9, 1907. The plant was turned over to the Water Department on Jan. 1, 1906, and has since been in charge of Mr. George G. Kennedy, the Department's secretary and superintendent. The operations of the plant during 1907 are stated in the annual report for that year to be very gratifying and show an improvement over the results obtained in 1906. The absolute removal of all turbidity and color contained in the river water is in itself an evidence of the careful working of the plant and the watchfulness of those in charge in noting the frequent and sometimes very sudden changes in the character of the raw water. The elimination of 99.59 per cent. of the bacteria in the river water, the average for the year, and the almost complete removal of B. coli, is of far more importance from the standpoint of health.

The turbidity in the river water during the year ranged from 3 to 2,600 parts per million; color, 0 to 40; alkalinity, 3.5 to 88; and bacteria, 160 to 160,000, an average for the entire year of 76 parts turbidity, 13 parts color, and 10,713 bacteria. The filtered water contains no turbidity, no color and an average of 44 bacteria. Every month in the year, with the exception of February, when an entirely new condition presented itself, showed an average number of bacteria remaining of less than 100 and out of all the counts made but 33 during the entire year were more than that number.

During January the absence of sufficient alkalinity in the river water made it necessary to use carbonate of soda to increase the temporary hardness sufficiently to decompose the sulphate of alumina. This was the first time since the plant was started that this condition existed and it occurred again in March. Since then, however, there has always been enough alkalinity found and during the low stage of the river in August there were as high as 88 parts present.

The total amount filtered during the year was 4,068,656,500 gal., of which 3,961,556,350 gal. were delivered to the pump and 107,100,150 gal. or 2.6 per cent. of the total were used in washing the filters.

The operating expenses were $20,783.59, made up of the following items: Alum, $6,205.89; soda, $293; coal, $2,306.46; oil and waste, $285.72; supplies, $874.32; repairs, $913.96; laboratory, $1,616.80, and labor, $8,287.44. The average cost per million gallons of filtered water delivered to the pumping station was $5.23, the cost of alum being $1.56; soda, 7 cents; coal, 58 cents; oil waste, 7 cents; supplies, 22 cents; repairs, 23 cents; laboratory, 41 cents, and labor, $2.09.

The sinking fund appropriation for the filtration loan was $10,333.33, interest, $10,850, State tax, $1,240, making the fixed charges $22,423.33, and the charge per million gallons $5.62. The total expense for filtration was $43,203.92, and the cost per million gallons $10.88.

The operating expenses are slightly higher than for 1906, caused by the average use of one-tenth of a grain per gallon more alum, the necessity of using soda, the shortening of the runs of the filters causing the use of more filtered water in washing and more coal, the reaching of about the nominal amount for repairs and a slight increase in wages for part of the employees.

The increased use of alum and shortening the runs between washing were due to the knowledge gained by experiments made last year. The benefit of these is shown in the general results.

The machinery, which was described in detail on March 9, 1907, gave no trouble and no expensive repairs to it have been necessary. A sufficient number of the different sizes of four-way cocks were purchased to enable any leaking ones to be taken out and refitted and duplicate orifice plates were procured. The valves and screens in the coagulant mixing tank and valves and fittings in the solution pump were renewed. Additional cocks were placed on the piping to the different operating tables to facilitate repairs. Sides 6 in. high were placed on the wash troughs of No. 12 filter and one 4 in. high was put on No. 4 to prevent flooding over the rear of the troughs when washing is going on and to give a more uniform wash. These experimental sides have proved that better and more uniform washing can be secured by extending the sides of all the troughs at least 6 in. A recording pressure gauge was placed on the wash line to check the washing operation and a governor was attached to the auxiliary pressure pump.

Samples of sand from each filter were taken in deep sections and at no place was any gravel found, demonstrating the fact that the gravel placed to protect the underdrain system had not been disturbed. Measurements of the depth of the sand have been taken occasionally and practically no sand has been lost. This is also confirmed by the absence of sand in the clear wells.

The sedimentation and coagulating basins were cleared twice. The removal of this heavy material, which is deposited immediately below and around the concrete force main, has been a matter of some inconvenience, it being too heavy to flush through the sewer. It was prior to this time taken out by hand and with the use of a portable sand ejector. The former method is expensive and the ejector too small to do the work quickly. To overcome this difficulty a 20-h.-p. gasoline engine connected by belt to a centrifugal pump with a 5-in. suction and a 4-in. discharge was purchased and mounted on a covered scow. With this outfit the sand is pumped from the basin and delivered over the top of the dyke at a saving in time and expense that is satisfactory. This pump has been used in one cleaning and changes that suggested themselves while in operation will be made and they are expected to result in greater efficiency.

During the year the preliminary treatment of the water in the sedimentation basin has been continued and the knowledge gained last year by dividing the coagulant has been added to. The average application for the entire year was about half the amount to the water as it was pumped to the basin and the balance as it entered the secondary basins. The average elimination in the basin for the year was 57.96 per cent.

At times when the turbidity and bacteria are both low no coagulant is applied to the water in the basin, but at all other times the dose is divided. During March when the turbidity averaged 10 parts and the bacteria 25,000, the elimination with the divided dose was 55.45 per cent. At that time for a short period the coagulant was applied only in the secondary basins, and the average removal in the basin in the 7 days that no coagulant was used was 16 per cent.

The treatment of the water present in parts of February and March had difficulties not before encountered. The river at that time was frozen over and the raw water contained about five parts turbidity, no color, and bacteria running from 500 to 20,000.

Ordinarily, in summer at least, a satisfactory elimination of bacteria could be obtained by an application of 0.5 or 0.6 grain per gallon in the secondary coagulating basin, but 1.5 grains applied there did not give the results sought. Neither did the same dose put in as the water was pumped from the river, allowing about eight hours sedimentation, give the necessary precipitate to render the elimination satisfactory.

Different processes were tried in mixing the alum, in using hydrated lime, in applying initial doses of alum and alum and clay to the filters immediately after being put in service, but none of these gave results compared with those obtained from the plant at other times. The initial dose of alum and clay repeated at intervals of one half hour showed some improvement and led to the application of clay direct to the water as it was taken from the river and pumped to the basin.

A barrel was fitted with a 1-in. water pipe with four perforated lateral connections near the bottom and a 2-in. outlet pipe near the top delivering the mixture into the pump well. A partition was put in the barrel to allow a good mixture to be obtained. A cock and valve were put in the supply pipe, the cock to turn off the supply and the valve to regulate the flow. In this barrel clay was mixed with the water in such quantities that with the occasional stirring the water would be heavily charged and enough of the mixture furnished to increase the turbidity of the raw water to about twenty parts per million.

Beginning with the use of this applied turbidity the number of bacteria in the filtered water decreased. After using the same dose of alum and 1 ½ grains per gallon as had been applied before the clay was tried and securing the comparative results, the alum was cut to one grain with the intention of further reducing it and obtaining the records from the different doses. It was also intended to apply the alum in a divided dose and in the small basins. Unfortunately after a few days' run on the one-grain application the ice broke up and the turbidity in a few hours reached 3,000 parts. The experience gained in this short period will be added to by further tests when the same conditions are encountered again and the advantages or disadvantages of the use of clay thoroughly worked out as the knowledge obtained in the use of it the few days surely justify further experimenting. Several kinds of clay were tried, but the one that made the best mixture was the material red brick are made from. The report contains a detailed table of the results.

The same program in the laboratory work has been followed since the filters were started. Three samples each of the river, filtered and tap water are taken each day and the turbidity, color and alkilinity determined. Two samples of the river, basin and filtered and one of the tap are plated for bacteria. Five 1-c.c. samples of the filtered and tap are sown each day and five 1-c.c. samples of the river water twice a week for B. coli. A chemical analysis is made each week of the raw and filtered water and a mineral analysis is run of all unusual waters so that the composition of all kinds of water will be known. The advantage of this work is very apparent, and with water as variable as the Susquehanna at this point no method of determining even approximately the bacterial results other than by these daily tests should be considered, the report states.

The same condition noticed last year in a fall in the turbidity and an increase in the bacteria has occasionally been found. The removal of all turbidity and color could be cheaply accomplished with the proper distribution of alum, in the handling of the filters, and by suitable application of air and wash water, but in no way could the safety of the effluent be guarded other than by the proper taking of samples and developing them. Even though the results are not known for two days after the water is filtered they are a guide to the operations.

Samples are taken from the effluents of the different filters at frequent intervals and all precautions necessary to keep the sand beds in the best possible condition are looked after.

Complete mechanical and quantitative analyses of the sand in the filters were made during the year.

The Telephone Standards of the United States Reclamation Service.

The U. S. Reclamation Service is building many telephone lines in connection with its irrigation enterprises and has found it advisable to adopt a standard system of construction. On the pole line an average of thirty poles per mile is used on tangents. The spans adjoining a pole on a curve at a corner do not exceed 150 ft. each for a pull of 5 ft., and the allowable length of span is decreased 10 ft. for each increase of 5 ft. in the pull up to and including a pull of 30 ft. When a bend made on a single pole produces a pull of more than thirty ft. the pole is braced and guyed and the adjoining spans do not exceed 100 ft. each, or such a bend is made on two poles and the lengths of the adjoining spans adjusted with the foregoing provisions relating to span and pull. The term pull means the perpendicular distance from the pole under consideration to a straight line joining the two adjacent poles. When a span of from 200 to 250 ft. is necessary, the adjoining spans do not exceed 100 ft. each, and where a span of from 250 to 500 ft. is necessary, the adjoining two spans at each end do not exceed 100 ft. each. On uneven ground the spans are so chosen and the poles so set as to avoid abrupt changes in the direction of the wire line vertically.

Telephone poles are in general 5-in. poles 25 ft. in length. At crossings of highways, railroads and gullies 6-in. poles of requisite length may be used. The poles are cut from growing red or white cedar trees, and are peeled, neatly trimmed, well seasoned, and reasonably sound. Butt rot in the center, including small ring rot outside of the center, the total of which does not exceed 10 per cent of the area of the butt, is permitted. Sweeps not exceeding 1 in. for every 5 ft. in length of pole are permitted. The tops of seasoned 5-in. poles measure not less than 15 in. in circumference and those of 6-in. poles not less than 18 in. If the poles are measured when green 5-in. poles must be not less than 16 in. in circumference at the tops and 6-in. poles not less than 19½ in. The top of each pole is trimmed to form a right-angled roof and painted with two coats of iron oxide paint.

On tangents the poles are set in a vertical position, and on curves and at corners they are raked 10 in. for a pull less than 5 ft., 15 in. for a pull of from 5 to 10 ft. and 25 in. for a pull of more than 10 ft. Each pole hole in earth is 5 ft. in depth and dug of sufficient size to admit of tamping around the entire perimeter of the pole. Where the line crosses solid rock, pole holes are blasted to a depth of 3 ft., unless such solid rock can be covered by a single span not exceeding 250 ft. When the hole is filled, earth or rock is firmly packed about the hole to a height of 1 ft. above the original ground surface.

Braces are 5 in. in diameter at the top, long enough to attach to the pole at two-thirds its height above the ground, to make an angle of 30 deg. with it and to extend into the ground at least 4 ft. measured along the brace.

Each brace is set in the ground at least 3½ ft. in vertical depth. The braces are cut slanting at the top to fit close to the pole and are attached to the pole with a ⅝-in. bolt supplied with a washer at each end. This bolt is placed at the lowest point of the joint. In fitting the brace to the pole all trimming is done on the brace.

Guys are No. 6, B.W.G., galvanized steel wire. Guy anchors in earth consist of galvanized cast iron plates and galvanized iron rods. Each cast iron plate is 8 in. square and ½ in. thick and is provided on the lower face with a cylindrical lug at the center having a diameter of 2 in. and a height of 1½ in. and with diagonal ribs ½ in. thick. Each galvanized iron rod is ⅝ in. in diameter and 6 ft. in length and is provided at the upper end with a suitable eye and a wire rope thimble for a ¼-in. rope and at the lower end with U. S. standard threads and a galvanized iron nut. Guy anchors in rock consist of galvanized iron rods of the combination eye-and-wedge-bolt type 1 in. in diameter and 18 in. in length, each provided with a suitable wedge and a wire rope thimble for a 14-in. rope.

Each guy is attached to the pole immediately below the bracket by making two turns around the pole and wrapping the end eight times around the guy, and is secured to its rod by passing around the thimble and terminating on itself in eight turns. The turns about the pole are secured by at least three 2-in. galvanized iron staples. The angle between the guy and its pole is as nearly 45 deg. as is practicable. Holes for anchor plates are dug at least 3½ ft. in vertical depth.

On tangents and curves having pulls less than 10 ft. double side guys are used about every 1,000 ft.; and on curves or at corners where the pull is from 10 to 30 ft. each pole is provided with a guy or brace. On curves and at corners each pole at which the pull exceeds 30 ft. is provided with either a guy or a brace placed in the plane of each of the adjoining spans and the adjacent poles are provided with appropriate supplemental bracing or guying. At least one head and one back guy is installed on every mile of line. Additional head and back guys or braces are used wherever the slope of the ground, length of span, change in direction or extra pole height at road crossings requires them for stability.

Pony telephone side brackets 1½ x 2 x 10 in. are used. They are made of the well-seasoned, sound, straight-grained oak, free from knots and sapwood, and are painted with two coats of iron oxide paint. Each bracket is fastened to the pole with one 40d and one 60d galvanized wire nail in such a position that the base of the bracket is about 14 in. below the top of the pole. Where the change in direction of the wire at any pole is more than 60 deg., an extra bracket is used. Brackets on ground-circuit lines are placed on the same side of all poles except on curves or at corners, where they are so placed that the strains produced by the wires will tend to press the insulators toward the poles.

On tangents of metallic circuit lines the brackets are placed one on each side of the pole and on curves and corners they are so placed that the strains produced by the wires tend to press the insulators toward the poles. The top bracket is so placed that its base is about 14 in. below the top of the pole, and the bottom bracket so that its base is 12 in. below that of the top bracket, except on transposition poles on tangents. On transposition poles on tangents the brackets are at the same elevation, so placed that the insulator for each wire is as nearly as practicable on a straight line between those for the same wire on the adjacent poles. On transposition poles on curves the bracket is so placed that the transposition insulator is as nearly as practicable on a straight line between the insulators for each wire on the adjacent poles.

Standard pony, glass, 10-ounce insulators and two-piece transposition insulators of equivalent strength shall be used.

The line wire is No. 12, B.W.G., galvanized iron wire of the quality known as "Best Best," having an average resistance at 68 deg. Fahr. not to exceed 33½ ohms per mile. The wire weighs approximately 165 lb. per mile, has an ultimate tensile strength of not less than 545 lb. and is capable of withstanding at least fifteen twists about its axis in a length of 6 in. It must be capable of elongating 15 per cent without breaking, after being galvanized. The diameter of the line wire is between 0.113 and 0.106 in. The galvanizing consists of a coating of zinc evenly and uniformly applied in such a manner that it will adhere firmly to the surface of the iron. Clean dry samples of the galvanized wire must appear black when they are four times alternately immersed for one minute in a saturated copper sulphate solution and then immediately washed in water and thoroughly dried.

The wire is strung with as few joints as possible and is joined by twisting the wires for a distance of about 3 in. around each other two complete turns and soldering, the end of each wire terminating in five tightly fitting contiguous turns around the other wire. The line wire is tied to the insulators with No. 12 galvanized iron wire cut in suitable lengths. The line wire is first laid in the groove of the insulator on the side away from the pole, after which the tie wire is passed entirely around the insulator and line wire and terminated at each end in five tightly fitting turns around the line wire.

In general a transposition of the line wires is made once in each mile. On tangents each transposition is made without the use of transposition insulators by interchanging the wires laterally in one span and vertically in the two succeeding spans. On curves each transposition is made by the use of a transposition insulator.

Lightning rods consisting of No. 12 galvanized iron wire are installed throughout the line at intervals of about 1/3 mile. Each rod is located about one-fourth the distance around the pole from the bracket and is attached to the pole with 2-in. galvanized iron staples. The upper end of each rod projects about 3 in. above the top of the pole and the lower end terminates beneath the butt of the pole in a flat coil containing about 6 ft. of wire.

A lightning arrester is installed on each line pole at which the current is transferred from the line wire to a station wire. The arrester is of the double-pole, lightning and sneak-current type, with adjustable and removable carbon blocks mounted upon porcelain bases and has fuses to protect it from lightning and sneak currents. The arrester is connected with No. 12 galvanized iron wire to any existing water pipe system near by or to a galvanized iron ground rod ½ in. in diameter and 6 ft. in length driven into permanently moist earth. The connecting wire is carefully soldered to the water pipe or to the ground rod.

The current is carried into buildings on No. 18 rubber-insulated copper wire covered with black braid saturated with waterproof compound and carried on porcelain knobs having a diameter of not less than 1½ in. The return pole of each instrument on ground circuits is connected by means of a similar wire to any existing water pipe system nearby or to a galvanized iron ground rod ½ in. in diameter and 6 ft. in length driven into permanently moist earth. Inside wiring consists of No. 18 rubber-insulated copper wire covered with braid of a greenish color. Where wires pass through walls and partitions insulated bushing is provided.

The telephones are the long-distance bridging type, each comprising a granular carbon transmitter, a two-cell battery, a bi-polar hand receiver, a hook switch, a ringer of 2,000 ohms resistance and a magneto generator capable of easily operating at one time all of the ringers on the line.

Tests of Quick-Action Air Brakes of the Westinghouse type were made during the past summer on the Hungarian State Railroads. The train was composed of 71 box cars with three passenger coaches interspersed for purposes of observation and two testing cars completely equipped with recording apparatus. Preliminary tests were made, the brakes being applied 275 times, with no injurious shock or parting of the train. The train was hauled by one and then by two locomotives and all the tests are said to have been satisfactory. Both Austrian and German railroad officials were present at the final tests.

A Hydro-Electric Development in Utah.

A hydro-electric development embracing various features of design, construction and operation which are more or less departures from usual practice has recently been placed in operation in the Utah district of the Telluride Power Co. This development is in a system including four other hydro-electric stations that supply power to the extensive copper mining and smelting operations and to numerous cities and towns in the vicinity of the Great Salt Lake, and for various other purposes. A fifth large development now under construction will be included in the same system, while a sixth one, also still under way, will be operated separately. The power transmission system by which current is delivered from the four stations at present operated in conjunction to the different widely-separated consumers, is one of the most comprehensive in this country.

The original development of the Telluride Power Co. in this district was on the Provo River, 10 miles northeast of Provo, Utah, which is 38 miles southeast of Salt Lake City, but this development is not in service. The second development was also made on the Provo River, three miles downstream from the original one. The third development is on the Logan River, near Logan, Utah, 75 miles almost straight north from Salt Lake City. The fourth station is 23 miles south of Salt Lake City on an irrigation canal supplied from the Jordan River. The most recently completed project is the one on Battle Creek, 12 miles north of Provo. The large development now under construction, which is also to be included in the transmission system with the four other stations now in operation, is on the Bear River, near Grace, Idaho, 135 miles north of Salt Lake City.

Owing to the nature of the varied industries and purposes for which power is supplied from the transmission system, the load factor of the latter is remarkably high. At the same time, peaks occur in the load curve due to the operating demands of the various lighting systems which are furnished with current, and also to certain demands of the mines. Extensive investigations were made by the engineers of the Telluride Power Co. to determine the best means of providing for these peaks in the load curve, so the main stations could be operated continuously at practically the same load. All phases of the feasibility of installing a storage battery or an auxiliary steam station to furnish the extra power necessary were carefully considered in comparison with a hydro-electric development designed specially to supply the service required. The investigations fully determined that under the existing conditions the hydro-electric development could be installed on Battle Creek for about one-eighth of the cost of a storage battery capable of producing the same results. The development is also such that it can be operated at a low maintenance expense, as compared with the high cost of maintaining a storage battery, and will produce power much cheaper than a steam plant operating at a low load factor. Furthermore, the power required by the storage battery would have to be drawn from the generating stations, while the new development could be made in such a manner that the water could be stored at such times as the station was not in service and used at times of maximum demand. The station on Battle Creek was consequently built to provide for the peak-load service, although the amount of power available is such that it is expected to be able to operate the station so it will float on the transmission system and at all times furnish some current to the latter.

The source of the water power utilized in the development is a series of springs on the westerly side of Mt. Timpanogus, one of the principal peaks of the most westerly spurs of the main range of the Wasatch Mountains. This peak rises to an elevation of over 12,000 ft., and its top is covered with snow until late in the summer. Although the annual rainfall in the surrounding region is comparatively light, it comes largely in heavy rains, and as the steep sides of the mountains are practically free of vegetation, much of the storm water is carried away rapidly. The melting snow, however, largely percolates into the soil and appears farther down the side of the mountains in perennial springs, the volume of flow from which is remarkably uniform. The water from the streams having their sources in these springs is entirely appropriated for irrigation in the broad, flat valley at the base of the mountains. The rights under which this water is diverted have come to have a very great commercial value in the intensely irrigated region in which the water is utilized.

For that reason, it was necessary in making the development to avoid interference in any manner with these rights. This result has been fully accomplished by the methods adopted. The installation, therefore, shows how it is possible to develop the full efficiency of the available sources of water for power and for irrigation purposes, such as is becoming more and more essential in the great semi-arid regions of the West.

The principal springs which have been utilized in connection with the development are the source of Battle Creek and are on the side of the mountain, about 3,000 ft. above the valley. A wood-stave pipe line, 10,000 ft. in length, extends from these springs along a contour on the face of the steep foot-hills which form the deep, narrow canyon of the creek, to a regulating reservoir on the crest of a high, precipitous hill at the edge of the valley. A connection made to this pipe line 3,000 ft. from the upper end diverts into it the water from another spring forming the source of a tributary of the main stream. Additional springs in an adjacent canyon, at a considerable higher elevation, can also be made available by the construction of a branch pipe line. The regulating reservoir at the end of the wood-stave pipe line delivers to a force main extending down the steep hill sides to a generating station at the base of the latter. After the water passes through this station it is is discharged into a second regulating reservoir from which it is delivered to the stream again at the uniform rate of flow of the latter.

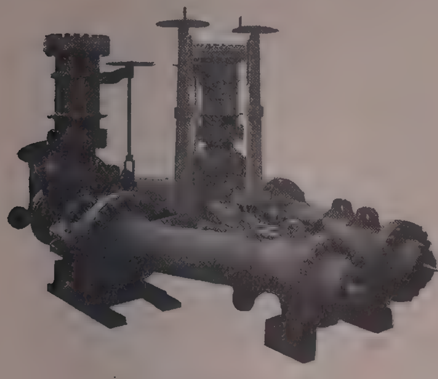
Intake and Wood-Stave Pipe Line.—The intake of the wood-stave pipe line at the upper springs is in a deep, narrow gulch, with the sides of the mountain rising abruptly to a great height directly above it. As a result, snow-slides occur frequently at the site, so the intake had to be built to provide against the possibility of destruction from this source. A concrete retaining wall, 8 ft. high, 30 ft. long and of large cross section, was built across the gulch to form a means of diversion. An intake well, 3 x 9 ft. in plan, was formed on the upstream side of this wall by a second heavy concrete wall, parallel with the first, and by two cross walls. All of these walls are on the solid rock ledge and are buried below the natural ground surface. A wide bank of boulders and gravel was placed on the downstream side of the main wall and covered with a double plank floor, fully anchored, as a protection against wash. The intake well is covered with iron bars, placed transversely and longitudinally to form a screen with 1-in. meshes. A 2-ft. flow pipe extends from the bottom of the well through the main retaining wall and the embankment to form a connection with the flow line. A 2-ft. waste pipe, fitted with a gate valve, is also extended through one end of the main wall.

General View of Station Building.

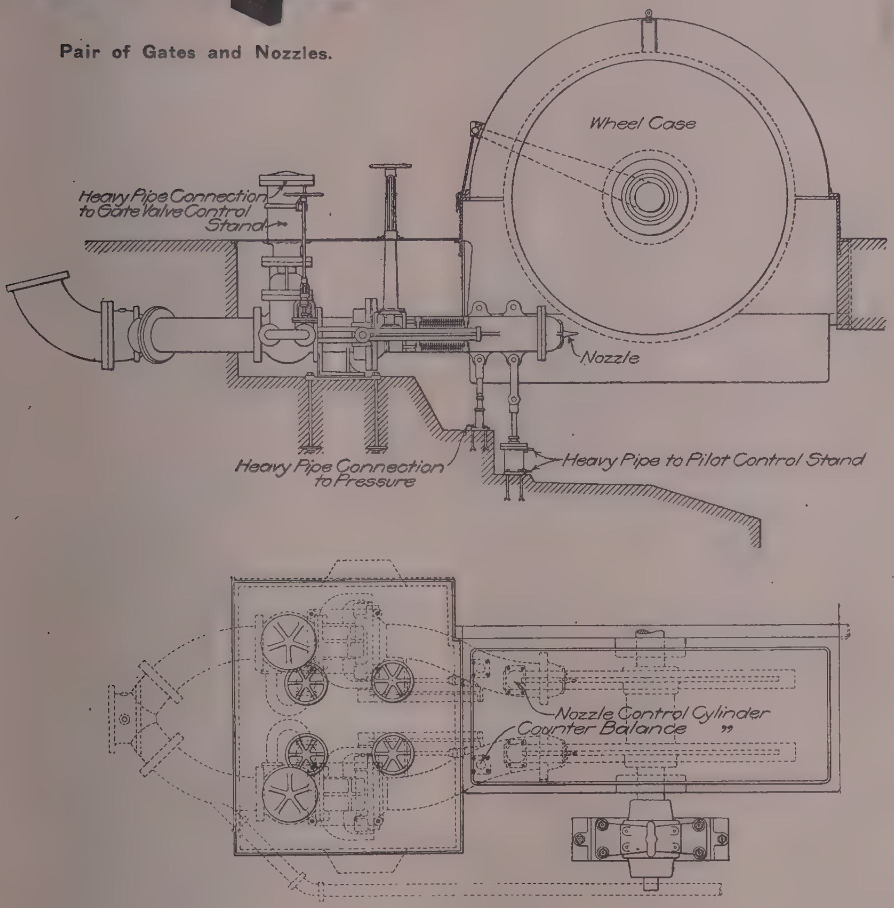
The 10,000 ft. of wood-stave pipe line leading from the intake to the regulating reservoir at the head of the pressure line is 2 ft. in diameter and is laid on a uniform grade of 0.34 per cent. The pipe line is in a bench cut in practically its entire length, following the contours of the ground around the sides of the hills, in order to maintain the established grades. The gulch of the stream from which water is diverted into the line by the connection 3,000 ft. from the upper end is crossed by an inverted siphon; a second gulch, about 2,000 ft. further along, is also crossed in the same manner. These siphons are both made of wood-stave pipe, with steel connections at the break in grade on both sides of the gulch and at the bottom, a drain valve also being provided at the latter in each siphon. The pipe is normally of 2 x 4-in. staves, with 9/16-in. round steel bands spaced 12-in. apart; on the siphons and at curves this spacing is reduced as required. The rough topography of the sides of the hills on which the line is laid necessitated the introduction of several extremely sharp curves of great angle. At the worst of the curves, short sections of steel pipe were used at the apices of the angles.

A chamber containing a measuring weir and an over-flow spillway which controls the maximum level of the water in the upper regulating reservoir, is placed on the wood-stave pipe line about 400 ft. from that reservoir. This chamber consists of an open timber box, 6 ft. wide and

57 ft. long, with its axis concentric with the axis of the pipe and the bottom just below the invert of the incoming pipe. A weir box, 6 x 13 ft. in plan, is placed in the upstream end of the chamber, with a weir crest in it 10 ft. above the invert of the pipe. The latter delivers to a riser which overflows into this weir box, so the entire wood-stave pipe line is maintained full of water under pressure at all times. The weir is provided to measure the flow in the pipe line, in order that the discharge from the station below may be properly distributed. The flow over the weir passes into a continuation of the open box, and then into the section of the pipe line extending to the reservoir. A spillway, 16 ft. wide, is cut on the outer side of the box, with its crest at the maximum high-water level in the reservoir, for which it acts as an overflow. The discharge from this spillway falls into a natural water-course, and is carried directly down the side of the hill. The banks of the elevated reservoir are thus entirely protected from danger of wash such as might be introduced by an overflow arrangement in them.



Pair of Gates and Nozzles.


Wheel Case
Heavy Pipe Connection to Gate Valve Control Stand
Nozzle
Heavy Pipe Connection to Pressure
Heavy Pipe to Pilot Control Stand
Nozzle Control Cylinder
Counter Balance "

General Arrangement of Nozzles and Water-Wheels.

Regulating Reservoir.—The regulating reservoir has a capacity of 265,000 cu. ft., and is built partly in excavation and partly in embankment, close to the crest of the steep hill above the power house. It is built to fit the ground, but is nearly a 125 x 275-ft. rectangle in plan. The embankments are 10 ft. wide on top, and have 2½ to 1 slopes on the water side and 2 to 1 slopes on the outside, being made fully ample to insure against danger of breaks in the rather precarious position occupied. The water is admitted at one end of the reservoir and taken out at the other. The outlet is a 20-in. pipe laid under the embankment and controlled by a gate valve inside the toe of the inner slope of the latter.

Pressure Pipe.—The outlet from the reservoir connects with the power station below by means of a pipe line. This pipe line has a total length of about 5,200 ft., the difference in elevation between its upper and lower ends being over 1,768 ft. The first part of the line for nearly 1,600 ft. from the reservoir is laid on a comparatively moderate grade, the drop in this distance being 288 ft. The remaining 3,600 ft. has a drop of nearly 1,400 ft., which is obtained at a quite uniform grade on the nearly straight, steep sides of the hill.

The upper 1,643 ft. of the line, starting at the reservoir, is of riveted-steel pipe with riveted joints. The diameter of the pipe in this distance varies from 30 in. at the reservoir to 26 in. at the lower end of the section of the line in which it is used. The thickness of the shell is increased from 0.134 in. at the upper end to 0.3125 at the lower end of this section, as the pressure is increased. This riveted pipe was built according to usual practice in design and construction by the Springfield Boilers Works, of Springfield, Ill.

The balance of the line is lap-welded steel pipe, in 30-ft. lengths, and was built by the Actiengesellschaft Ferrum, of Germany, being shipped by water to Galveston, Texas, and then by rail to the work. The first 1,400 ft. of the lap-welded pipe, with static heads gradually increasing from 290 ft. to 1,100 ft. has a special form of riveted joint between the lengths. The balance of the joints are a specially designed type arranged to carry the static heads of from 1,100 ft. to 1,768 ft. with a good factor of safety. The caulking of the flange joint used for the high heads is such that leaks are almost impossible so long as the bolts between the sections hold. The outside of the lap-welded pipe varies from 24-in. in diameter at the upper end of the section in which it is used to 20-in. at the power house. The thickness of the shell ranges from ¼-in. at the high end of the lap-welded pipe section to ⅞-in. at the power house.

A practically straight alignment and a uniform grade were obtained for the first 2,900 ft. of the line up the hill from the power station, in which distance the highest pressures are encountered. In this distance, also, the pipe is laid in a trench and covered to a depth of about 4 ft. At the few slight changes in grade or alignment anchors were provided. These anchors each consist of heavy rod of Norway wrought-iron wrapped around the pipe and attached at both ends to the solid ledge rock. The pipe terminates at the bottom in a large, heavy block of concrete, which forms the base of the rear end of the station building.

Station Building.—The station building occupies a remarkably commanding situation at the base of the high, steep hill down which the pressure pipe is laid. The ground slopes away in front of the building to the broad irrigated valley below, with Utah Lake at one end of this valley and the Oquirrhi Mountains rising abruptly on the opposite side of the valley from the station. As may be seen from the accompanying illustrations, the station building has an aunusually attractive exterior appearance, designed to be in keeping with the surroundings. The building is a high one-story structure, 50 x 95-ft. in plan, with brick side walls on a concrete base, and with a low roof carried by steel trusses. The rear end of the structure is in an excavation in the solid rock side of the hill on which the pressure pipe is laid, while the front end extends out on a slight slope in the ground and has a broad portico with six large Ionic columns supporting the roof over this portico.

The entrances to the building are on the sides, the front wall back of the portico being blank. The interior is divided into a main room, 32 x 80 ft. in plan, for the equipment, and a 16 x 50-ft. room at one side for a machine shop and storage. The interior walls are coated with white plaster, finished smooth; the floors are concrete. A good amount of window space in the side walls, together with the interior finish, produce good lighting effects during the day. At night a uniform distribution of light is obtained by placing electric lamps in the roof trusses, with shades which throw the light against the white ceiling so it is reflected back into the room without any glare.

Generating Equipment.—The main room of the building contains a single water-wheel-generator unit in which the entire ultimate capacity of the station is embraced. This unit occupies the rear end of the room, the pressure pipe being brought through under the rear wall in the solid mass of concrete at its lower end. The hydraulic part of the unit is a double Pelton water-wheel, mounted on a single shaft and in a single case. The wheels are on an extension of the shaft of a 2,400-kw. 2,300-volt 60-cycle General Electric generator. The unit operates at a normal speed of 300 r. p. m. The generator has an overload capacity of 4,000 electrical horse-power, which can be maintained for 4 hr. without heating, and which amount of power the water-wheels are capable of developing.

The shaft of the unit is mounted on three bearings, one on each side of the generator and one on the opposite side of the wheels from the generator. The outboard generator bearing, built by the Pelton Water Wheel Co., is 9-in. in diameter, and is of the machined ball-and-socket type. The bearing is in a tight case partially filled with oil, which is carried up on the shaft by loose rings riding on the latter, the boxing having a lower half only.

Each water wheel is a forged steel disk, on the periphery of which are mounted twenty-four of the highest type of cast-steel Pelton tangential buckets. The wheels operate under an effective head of 1,750 ft. at low stages in the reservoir, and under maximum effective head of 1,775 ft. Water is supplied to each wheel through a separate Pelton needle deflecting nozzle. The size of the stream applied to the buckets is hand regulated by means of the needle part of the nozzle through a standard mounted on a floor directly over the rear end of the nozzle. For changes in the speed of the wheels, each nozzle is deflected by means of a Pelton pilot control apparatus mounted on the floor in front of the unit.

A diagrammatic sketch of this pilot control is shown in one of the accompanying illustrations, in which the control proper is set up as in the building, but the nozzle is placed directly under it for convenience of illustration. The control apparatus consists of a floor stand which carries at the top a hand wheel and a traveling nut on a horizontal screw, with a pointer for indicating the position of the nozzle. Within the floor stand is a piston valve, levers and links. The piston valve is piped to a hydraulic cylinder located under the deflecting nozzle of the water wheel. A piston in this cylinder is connected to the nozzle by means of links. Fastened to this nozzle is a cord which passes over a series of pulleys and terminates at the pilot control in a counterbalance of sufficient weight to keep the cord taut. This cord is fastened to the lever *AD* in the control stand, at the point *A*.

In operation the apparatus then works as follows: To put a stream on the buckets, turning the hand wheel in a clock-wise direction moves the traveling nut *D* back from the hand wheel to the point *C*. The lever *AD* fulcrums on the point *A* and moves the piston of the valve inward. This allows the pressure to escape to the bottom of the hydraulic cylinder at the nozzle and opens the top of that cylinder to a discharge port. As soon as pressure is brought to bear on the outside of the piston in the cylinder, the deflecting nozzle is forced upward. Simultaneous with this movement the weight drops and moves the fulcrum *A* to the point *B*, which again throws the piston in the piston valve of the control outward, bringing it to the same point as it was before the operation was started.

If it is desired to throw the water off the buckets in order to shut down the wheel, this may be accomplished by turning the hand wheel on the control in an anti-clock-wise direction so pressure is applied to the top of the piston in the cylinder under the nozzle and released at the bottom.

The pair of deflecting nozzles for the two wheels are attached to a Y-connection at the end of the pressure pipe imbedded in the mass of concrete under the rear end of the building. Each branch of the Y is fitted with a hydraulically operated gate valve, placed in a covered pit in the concrete at the rear of the wheel case. The operation of each of these valves is controlled by a hand wheel mounted on a standard on the floor at the rear of the unit. In order to avoid any disastrous effects from water-hammer in the pressure pipe, caused by too rapid closing of these valves, or by other conditions, a relief valve is placed in a connection to the line directly back of the junction of the branches of Y.

The discharge from the nozzles when diverted from the buckets is directed against a curved baffle plate set in the end of the concrete which forms the pit under the wheels. This baffle plate is arranged so the streams strike it tangentially and their direction is changed to 90 deg. The stream is thus thrown into a deep splash pit where its remaining force is absorbed and the water delivered to the tail race practically quiet. The tail race from the pit leads under the building to the regulating reservoir below. The hydraulic equipment was designed and built by the Pelton Water Wheel Co. in San Francisco.

The regulating reservoir is circular in plan, with a diameter of 180 ft. and has a capacity of 400,000 cu. ft. It is also partially in excavation and partially in embankment, without lining, as the embankments are water-tight.

Operating Conditions.—The minimum amount of water available from the springs which have been developed is about 10 cu. ft. per second. This amount of water is, of course, insufficient to operate the station continuously to the full capacity of the generator. It is, however, the intention to supply only a small amount of power to the transmission system, except during maximum demands on the system for power. Meanwhile water will be stored in the regulating reservoir at the head of the pressure line, and then drawn as the occasion demands. With the present available water supply, the station can thus be operated to the full capacity for 6 hr. each day. Later, when the other springs are developed, the amount of power available will be practically doubled.

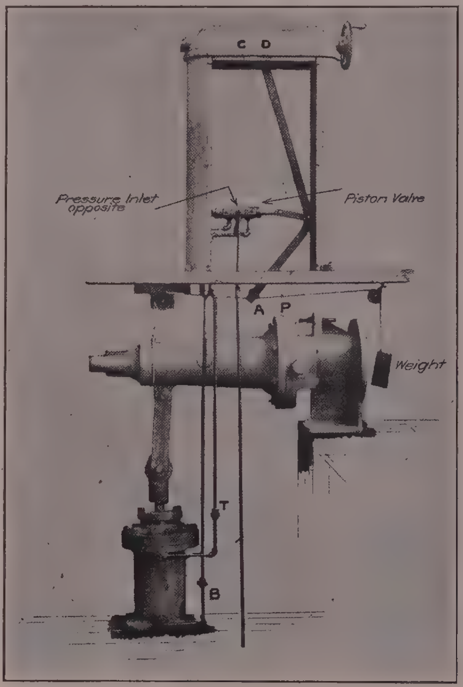


Diagram of Pilot Control.

The regulating reservoir below the station permits the water to be used in this manner as desired, without in any way interfering with the rights of the irrigators in the valley. The water entering the reservoir on the hill is measured, and the quantity discharged from the reservoir below the station into the creek again is also measured. Any leakage in the system is thus determined and at once located. When the water is diverted into the pipe line from the springs in the adjacent canyon it will be separately returned below the station to the valley of the stream supplied by those springs.

Construction.—The construction of the wood-stave and pressure pipes presented difficulties of considerable magnitude due to the trouble of delivering the materials up the steep hillsides. A 36-in. gauge tramway track was laid up the steep hill side close to the pressure pipe, the grade on this track being as steep as 30 deg. from the horizontal. A 25-h.p. hoisting engine was installed at the base of the incline and hauled a four-wheel truck up the latter by means of a ⅝-in. steel cable rove through a sheave wheel attached to a buried anchor at the top of the incline. All of the materials of construction and the men were thus transported up the hill, which is so steep as to make climbing a laborious task.

The bench cut in which the wood-stave pipe is laid from the intake at the springs to the upper regulating reservoir was made along the sides of the hills in advance of the pipe laying. The latter was started at the intake and carried forward continuously, the pipe being built in place. The staves and bands were delivered to the head of the incline, where they were loaded on a special wagon on which they were hauled to the work. This wagon had narrow trucks built to travel on the narrow cut. The rear truck was also arranged so it could be turned by hand, like the rear truck of a fire-ladder wagon, in order to enable the wagon to be operated around the sharp turns in the line of the pipe grade.

The regulating reservoir was built with teams and scrapers, the teams being brought up to the top of the hill each day by a round-about trail. The scrapers and all material used in building the reservoir were delivered on the incline.

The transportation of the heavy steel pipe up the steep grades of the incline involved much hazardous work. The 30-ft. sections weigh from 2 to 4 tons each, and were hauled up over the incline one at a time on the truck, which had a heavy block of wood on each end cut to fit halfway up on the pipe. The section was also thoroughly lashed to the truck to hold it in place on the steep grades.

The pipe was delivered from the truck at three points, at each of which points a bench cut was made in the hillside, leading from the tramway to the site the pipe was to occupy. After a section of pipe was unloaded from the truck it was slung by a cable attached to an anchor above and was thus held from sliding down the hill until it had been placed in the line. All of this hazardous work was accomplished without injuring a man.

The Fire at the Dayton Motor Car Company's Building.

On Feb. 20, a fire broke out on the fourth floor of a new concrete building of the Dayton Motor Car Co., Dayton, Ohio. This floor contained the upholstering and final assembling departments and the materials there caused such a hot fire that some of the sprinklers and steam-heating pipes were bent and twisted. Fire doors had not yet been placed between this building and an adjoining brick structure, and the flames accordingly passed to the latter. When this happened the firemen concentrated their attention on it and succeeded in checking the fire there after the upper two floors and their contents and the roof had been completely destroyed. The extent of the damage to the new building consists of the destruction of perhaps half of the window sash in the fourth story, and of about half the flooring, together with the piping before mentioned. The fire was communicated to the fifth floor to a slight extent, but did little damage to its contents. The owners state that they consider the damage to this building amounts to little or nothing. This building was designed in accordance with the Kahn system of construction and was built by the Keppele Hall Co., of Dayton. The latter made an examination of the structure immediately after the fire and reported as follows concerning it: "The only damage that we have been able to discover is that the concrete on the corners of some of the columns and the edges of the beams over the hottest part of the fire has become vitiated so that it can be knocked off with a hammer. There is no evidence of any deflection or cracking of any of the beams and girders, and as far as we can judge the steel has not been affected in any way. The cement floor on the fourth story blistered and cracked over half the area on account of the intense heat and resultant expansion, but the slab below remains uninjured."

The Application of Electric Power to Pulp and Paper Mills.

By LeRoy M. Harvey, of Allis-Chalmers Company.

The wonderful progress made in the last decade, particularly during the last five years, in the application of electricity as a motive power to all branches of commerce and industry, has awakened the interest of the whole manufacturing world to its possibilities, and the paper mill operator is to-day making a conscientious investigation into the results to be secured by the application of this power to his own particular branch of industry. The scheme of power transmission which has prevailed in paper mills has a parallel in that to be met with in any other factory of equal or greater size not already equipped with electric motors. A distinguishing difference, however, between the paper mill and the other types of factories is found in the fact that in possibly no other industrial establishment is the percentage of losses due to an inefficient system of power transmission so great as in the paper mill; and, as a consequence, in no other type of industrial establishment is the percentage of saving resulting from electrical equipment so large.

No line of improvement in paper-mill equipment will contribute more to the securing of low cost of production and high-grade output than the adoption of the electric system of power transmission. This is a very broad statement, but it can be substantiated by a careful investigation of the results obtained from mills which are actually equipped with the electric system. Naturally, the first question which arises in the mind of the mill operator is wherein will the use of electricity as a motive power lead to lower cost of production and a higher grade output. The answer to this question is found in a number of primary effects resulting directly from the use of the motor drive, each one of which bears its part in securing the final result above mentioned. These primary effects may be classified as follows: (1) Reduction of transmission losses, (2) greater reliability, (3) greater elasticity, (4) reduced cost of maintenance, (5) steady speed throughout the mill, (6) ideal conditions for the paper machine, (7) saving in space, (8) decreased chance of injury to employees, (9) greater cleanliness.

Reduction of Transmission Losses.—In every mill with old style equipment the quantity of belting, pulley, hangers and shafting is something appalling, and the losses of transmission through this complex system are very large. Actual tests show that these losses vary from 40 to 60 per cent of the power delivered at the engine or water wheel shaft; 50 per cent being a very fair average. This figure, of course, does not apply to the grinders or the beater shaft when driven direct, as is usually the case. The more complex the system of shafting and bolting becomes, and the greater the distance of transmission from the source of power, the more rapidly does the percentage of friction loss increase. In comparison with this we are able, with the electric system, to transmit power from the shaft of the prime mover to the shafts of driven machines with an average loss of from 20 to 25 per cent, from 3 to 5 per cent of this being in the wiring and the balance in the generators and motors. Moreover, we reduce the loss to this low point regardless of the complexity of the system or the distance of transmission.

A modern two-machine mill, with the prevailing tendency towards large size machines, will require outside of the grinders from 1,500 to 2,000 h.p. Assuming the minimum saving of 15 per cent on this, we shall have a net gain of from 225 to 300 h.p., a very considerable sum when reduced to the basis of dollars and cents. In a steam-driven mill this saving would be represented by the decreased consumption of fuel; in a mill where water is the prevailing power the saving will appear in the additional volume of water available for grinding pulp, or for extensions.

Greater Reliability.—Where the operation of any particular machine or line shaft is dependent upon that of a number of other shafts, with many belts intermediate between this machine or shaft and the prime mover, there is always the liability of an entire shut-down, due to the failure of one of the intermediaries. In a paper mill this possibility is increased by reason of the fact that many of the belts are large and very heavy, causing a great strain upon the shaft, hangers and pillow blocks and resulting in throwing the shafting out of alignment and heating the journal boxes, to say nothing of breaking the belts themselves. It should not be forgotten, either, that a shaft out of alignment rapidly increases the friction losses.

With the electric system there are no intermediaries. Each motor, with the machine or shaft which it drives, is really a separate unit, and, as the failure of the wiring is a most unusual occurrence, is dependent on nothing but the operation of the prime mover itself. The motor troubles, of which we occasionally hear, are in nearly every case directly traceable to poor engineering in laying out the installation or to negligence on the part of those employed to look after the electrical apparatus.

Greater Elasticity.—The term elasticity as applied to an electric system of power transmission is intended to convey the idea of easy expansion and application to all of the many power problems encountered in the modern mill or factory. If the mill operator wishes to install new apparatus he does not have to stop to figure out how he is going to get power to the new machines; he knows that all he has to do is to install a motor and run a wire to it.

Another phase of this elastic system lies in our being able to distinguish between the different types of power service required throughout the mill and to treat each individual case on its merits and in the manner calculated to secure the highest efficiency of operation. In the old system it was always a case of belting; but with the electric system we can either direct connect, gear or belt the motor to the driven machine, as may seem best. In general, for paper mills it is better to direct-couple wherever this can be done without too great an investment in the motor by reason of the necessity for very slow speeds. The scheme usually followed, and which we recommend, is to direct-connect the centrifugal pumps, Jordans, barkers, log saw, and variable speed shaft of the paper machines; gear all duplex or triplex pumps, rotaries, calenders and wet machines; gear or belt the conveyors, rag dusters and cutters; and belt the beaters, elevators and all group drives. The grinders, in our opinion, it is better to direct-couple to the water wheel shafts, although there are some who favor driving these also by direct-connected motors.

Reduced Cost of Maintenance.—Every one who has had experience with a complicated system of belting and shafting well knows what it means to keep it in running order. In the average paper mill much of the time of the mill-wright and his assistants is required for this work. In an electrically equipped mill, the chief engineer and his assistant can easily take care of the electrical apparatus, for all they have to do is to see that the bearings of the motors and generators are properly lubricated, and, in case the equipment is of the direct-current type, to keep the commutators clean and the brushes properly adjusted. With alternating-current motors, which have no commutators, there is nothing to require attention but the bearings. Burn-outs in the windings of the motors are practically unheard of, but even if they should occur, the motor can be repaired in less time and with less expense than is required to restretch a broken belt or replace a melted-out journal. The services of at least one man and possibly two or three are saved outright and there is practically no expense for supplies, as none are required except for extensions after the installation is completed.

Steady Speed.—One of the many drawbacks to the belt and shaft scheme of transmission lies in the constantly changing speed throughout the system. This change is not due so much to variation in the speed of the prime mover as it is to the effect of starting and stopping the various shafts or machines comprising the system. A heavy load, thrown on or off in this way, reacts upon the apparatus nearest to it on the system, instead of upon the prime mover as it should. With an electric installation, however, the effect of starting or stopping any motor is carried back to the switchboard which is connected directly to the prime mover, and, as the prime mover is always provided with a governing device to control its speed, the other machines on the system are not interfered with. There are many machines where a continued variation in speed becomes a serious matter, and at all such times such changes impair the running efficiency of the mill and tend to lower the quantity and quality of the output.

The paper machine itself is the very heart of the mill, and the successful operation of the auxiliary apparatus is of no avail if there is trouble at this point. Nothing contributes so much to the ideal conditions for operation as a steady speed, which can at the same time be readily varied, and uniform temperature in the steam which is used for drying. Both of these requisites are possessed by the electric system. We derive from the prime mover an almost constant speed. This speed, through the agency of the variable-speed motor which has proved so satisfactory in service, can be varied at the will of the operator over a very wide range, and at the same time the motor maintains practically a constant efficiency. Variable-speed motors on paper machines, in actual operation to-day, have a ratio of speed change of 2 to 1 under these constant conditions of efficiency, and it is entirely practicable to get as high as 3 or even 4 to 1. By the use of a controlling device and multiple voltage, although this slightly decreases the efficiency of operation, that ratio of speed change may be still further increased to 6, 8 or even 10 to 1. One of the most important features of the speed change lies in the fact that the successive increments of the change are very small; each step on the controller means a change of only 1½ to 2 revolutions on the motor or on the variable-speed shaft to which the motor is direct-coupled. The speed can be varied over the entire range without a shutdown, which means that the machine tender can change from one grade of paper to another, no matter how great a difference, without stopping the machine. The difficulties of maintaining a constant speed, when the machine is driven from an engine operated under a varying steam pressure and varying load, are to well known to require more than mention.

The single objection raised by some manufacturers to the electric system is with regard to the economy of the drive on the paper machine itself. They contend that as long as it is necessary to use steam for drying it would be better to drive the machines by engines and use their exhaust rather than drive by motors and dry by live steam. In a consideration of this point we should divide the mills into two classes: first, those whose initial power is water, and, second, those whose initial power is steam. We are certain that even the most ardent advocates of the use of steam engines and exhaust steam will admit the superiority of electric drive in the case of mills of the first class, for there can be no question that the generation of electric power from water is cheaper and more efficient than the generation of steam power from coal. The only argument, therefore, is with respect to mills of the second class. Many such mills, partially steam driven, could be placed in the water-power list by the adoption of the electric system, the power thus saved being equivalent to that produced by steam. Admitting, for the sake of argument, that in mills of the second class it is more economical to use engines on the machines, which contention is open to dispute, the many advantages of the electric drive are more than sufficient to outweigh the possible saving in fuel. Moreover, we see no reason why the exhaust from the main engine driving the electric generators could not be used for drying if desired; and if this is done the question of economy is wiped out entirely. Another contention which has been advanced by paper manufacturers who are using the electric drives on their machines and live steam for driving, is that the use of live steam permits maintaining a constant temperature on the dryers, resulting in a uniform sheet of paper of high finish, a condition which cannot be as easily secured by exhaust steam on account of the varying pressure in the line. If the mill be driven by water power, no engines whatever will be required; if by steam, the engines will be used solely to drive the electric generators in the power house. In either case the drying will be done by live steam taken directly from the boilers, and brought down to the proper pressure through a reducing valve. By this method we are assured of a constant pressure, which means a uniform temperature in the dryers of the machines. There is, of course, no reason, in a steam-driven mill, why the exhaust from the engines driving the generators cannot be used for this purpose if desired, but if the drying is done with exhaust steam, it is almost out of the question to maintain a uniform temperature, as the exhaust frequently drops to so low a temperature that it is practically water and of little value for drying. Admitting for the sake of argument, that it is cheaper to dry with exhaust than with live steam, which fact is open to dispute, the advantages of the live steam outweigh any possible saving in the use of the exhaust.

Saving in Space.—Doing away with so much shafting, with its accompanying array of pulleys, belts, hangers and pillow blocks, naturally relieves, to a great extent, the conjestion which exists in the average mill. As the motors are mostly direct-geared or coupled, very little space is required by them, thus permitting placing the various machines close together, and at the same time affording ready access to all. As the result, a large floor space is available for the storage of stock, and for storage in such a manner as to afford ready access, not only to the stock itself, but also to adjacent machinery.

Injury to Employees.—The protection of the lives and limbs of his employees is, naturally, one of the first thoughts of a manufacturer, and yet hardly a day passes but that we read of some operative getting caught by a belt, pulley or shaft and either losing his life or being seriously injured. Such accidents it is almost impossible to prevent where a system of shafting is in use—the two evils are co-existent. There is also a sequel to accidents of this character in the shape of damage suits which, under the employer's liability laws existing to-day, frequently results in large losses to the owners of plants. In a recent case of this kind the plaintiff, a mill hand, received a verdict of $15,000, which was confirmed by the Supreme Court.

Cleanliness.—"Cleanliness is next to godliness," says the old maxim, but in a paper mill cleanliness is of paramount importance, and nothing contributes more to a high-grade product than clean stock and a clean mill, particularly a clean machine room. Belts, pulleys and shafting are potent disseminators of dust, and the only safeguard against it is to do away with them all.

As an illustration of what can be accomplished by the adoption of the system advocated in the preceding paragraphs, a brief description of the new mill of the Watab Pulp & Paper Co., may be interesting. This mill is located on the Mississippi River at Sartoll, Minn., a few miles above St. Cloud, and was described in The Engineering Record of April 6, 1907.

The mill buildings are all of reinforced concrete and consist of a machine room and basement 72 x 280 ft., a beater room and basement 40 x 122 ft., wood room and basement 36 x 70 ft., boiler house 58 x 72 ft., pulp mill 32 x 152 ft., pump room 20 x 70 ft., and power house 32 x 72 ft. The boiler room contains two Stirling boilers which furnish steam for heating the buildings and for drying the paper. All the power used in the mill, with the exception of that for the nine grinders which are direct-coupled to water-wheels, is generated in the power house located near the center of the river immediately adjoining the grinding room. A dam 600 ft. long was thrown straight across the river and affords a head of approximately 17 ft.; the power house and grinding room form a part of the dam, and the remainder consists of gates and spillway of the ordinary rock-filled crib construction.

The generating equipment consists of three 600-k.w., three-phase, 60-cycle, 480-volt, alternating-current, revolving field generators, each direct-connected to a sextuplex water-wheel operating at a speed of 200 r.p.m. The exciting current for these generators is supplied from a 75-kw., 120-volt, direct-current generator, coupled to a single water-wheel or from a motor-driven exciter of the same capacity. Two motor-generator sets, each consisting of a 250-kw., 240-volt, direct-current generator coupled to a 480-volt synchronous motor supply current to the variable-speed motors in the machine room. The alternating system was adopted as being best suited to withstand the rigorous requirements of paper mill work and least liable to give trouble with motors when located in moist places so common in very mill. The current is distributed through a 13-panel blue Vermont marble switchboard arranged with wattmeters and ammeters so that an accurate log may be kept of the power required by each separate department. Thirteen feeder circuits carry current to 51 constant-speed alternating-current induction motors and to eight variable-speed direct-current motors.

The machine room contains two 154-in. Beloit machines. The variable-speed shaft of each machine is driven by a 250-hp. variable-speed direct-current motor coupled directly in the center of the shaft. This motor operates at a speed of 270 to 540 r.p.m., corresponding to a paper speed of from 300 to 600 ft. per minute. The entire variation is accomplished by means of resistance in the shunt field of the motor. The field rheostat controlling the speed of the motor has 138 steps, which means a change of approximately 2 ft. per minute in paper speed for each step. It must be borne in mind, too, that the changing of speed is accomplished without any loss of time whatever, as the controller is located on the machine room floor, about midway of the drying rolls, and the movement of the controller handle is but the work of a second for the machine tender. The rewinder at the head of each machine is also driven by a variable-speed 30-hp. direct-current motor having a speed range of 2 to 1. Two 7½-hp. motors of the same type, with 25 per cent speed variation, operate the shakes of the two machines. The only other direct-current motors in the mill are two of 5-hp. capacity with a speed range of 2 to 1, which drive special cutters in the machine room basement.

The group at the wet end of each machine, in addition to the shake, consists of a save-all driven by a 5-hp. back-geared induction motor, a suction pump driven by a 30-hp. geared induction motor, a fan pump with a 40-hp. direct-coupled motor, a machine pump with a 7½-hp. geared motor, and a machine chest agitator and flat screens driven by a 30-hp. belted motor. To this group belong also the broke beater driven by a 40-hp. belted motor and the broke beater pump driven by a 40-hp. direct-coupled motor.

The beater room contains six beaters and two "Majestic" Jordan engines. The beaters are driven in pairs, one right and one left, by three 100-hp. motors located in the basement. These motors have their shafts extended both ways, with pulleys on either end; outboard bearings are also provided to insure rigidity and freedom from belt slappage. Belts connect the motors directly with the beater pulleys. The drive for the Jordans is one of the most noteworthy in the mill. Each Jordan is directly coupled to a 150-hp. motor operating at 312 r.p.m. The base of the Jordan is extended to receive the motor, which is arranged to slide on rollers as the plug is moved in or out by means of the regulation hand wheel. In the beater room basement are located the stock pumps for supplying the Jordans, each driven by a 7½-hp. geared motor, and also the Jordan chest agitators driven by two 15-hp. belted motors. The controllers for starting and stopping all motors governing the supply of pulp to the beaters and Jordans are located on the beater room floor, so as to facilitate rapid handling of stock.

In the pump room are located the pumps controlling the water supply and those for handling the ground wood pulp. The entire water of the mill, outside of the boiler feed, is obtained through three 6-in. centrifugal pumps, each direct-connected to a 40-hp. motor. An underwriter's pump is used for fire purposes only. Two centrifugal pumps for pumping pulp from the grinders to the flat screens in the wet machine rooms are located in a pit beneath the pump room. Each of these is direct-connected to a 50-hp. motor. In this room are also the centrifugal Decker chest pump direct-coupled to a 40-hp. motor, the triplex pressure pump for grinders driven by a 40-hp. geared motor, the triplex back-off pressure pump driven by a 7½-hp. geared motor and the silver screen driven by a 5-hp. back-geared motor.

The wet machine room contains five wet machines, two deckers and twelve flat screens. The wet machines are each driven by a 10-hp. back-geared motor. The flat screens, which are located immediately back of the wet machines, are driven through friction clutches connected to a line shaft by means of a mitre gear, this line shaft being direct coupled to a 100-hp. motor. The deckers are driven by belt from the wet-machine shaft. A machine shop adjacent to the wet machine room is driven by a 10-hp. belted motor.

The wood room equipment consists of six barkers and a 60-in. log saw with the necessary conveyor. The logs used for making pulp are taken from the river to the saw by a log haul, which is driven by a 5-hp. back-geared motor. The saw and live rolls are direct-coupled to a 30-hp. motor, the coupling being of sufficient weight to act as a flywheel and thus reduce the actual power required for sawing. The sawed wood is carried to the barkers by a conveyor driven by a 10-hp. back-geared motor; this same motor also drives a splitter. The barkers are each driven by a 7½-hp. direct-coupled motor, the iron base of the barker being cast with a pedestal to receive the motor. The prepared wood is carried to the grinding room by a conveyor driven by another 10-hp. back-geared motor. A shaving fan driven by a 40-hp. belted motor blows the chips from the barkers directly on to the boiler grates. What additional coal fuel is required is carried in hoppers above the boilers. A 10-hp. back-geared motor drives a bucket elevator which fills the hoppers directly from the cars in which the coal is shipped.

The Watab mill has now been in continuous operation for nearly one year. It began making paper a few hours after current was first turned on, and has not been shut down since due to failure of equipment, a most unusual performance for a mill of this size. The complete electrical installation was furnished by Allis-Chalmers Co. and the design and specifications were prepared by engineers of the Allis-Chalmers Co. acting in conjunction with the mill superintendent and Mr. Samuel Holmes, paper mill expert and engineer.

An Ornamental Elevated Water Tank.

A 15,000-gal. elevated reinforced concrete water tank has been constructed recently at Katonah, N. Y., in connection with a private water supply system for the estate of Mr. Edwin Tatham. The tank proper is cylindrical in form, having a depth of 7 ft. and an inside diameter of 20 ft. It is supported on nine columns, one under the center of the tank and the others arranged symmetrically in the plane of the cylindrical surface. It is covered with a tin roof supported on radial wooden rafters with wide eaves. To conceal the character of the structure and to bring its appearance in harmony with the immediate surroundings, ornamental urns will be placed at each column in which will be planted vines, the foliage of which will ultimately cover the whole surface of the tank. The area enclosed by the columns will be paved with tiles and rustic seats will be provided so that the sheltered space can be used as a summer tea room.

The tank wall has a uniform thickness of 12 in. and is reinforced with a single thickness of Clinton wire cloth placed near its outer surface. Under the floor slabs are four radial girders arranged as shown in an accompanying illustration. Each of these girders is 18 in. wide and 12 in. deep, not including the thickness of the 12-in. floor slab. Each girder is reinforced with eight ¾-in. Ransome bars, six of which are placed in a plane near the under surface of the girder, the remaining two being placed just above this place, one in each side of the girder. Clinton wire fabric is placed across the bottom of each girder just below the rods and up each side and extending into the floor slab a short distance. The floor slab is reinforced near its lower surface with wire cloth in strips 4 ft. wide. A single layer of fabric was first placed across the floor in one direction parallel to one pair of the radial girders, and then over this a single strip was laid with its center line over the other pair of girders.

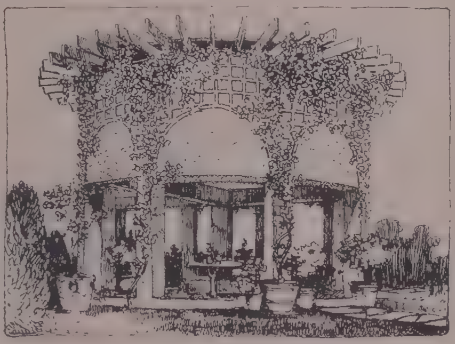
Each of the circumferential columns is 24 x 18 in. in section and 8 ft. high. Each column is reinforced with four ¾-in. Ransome bars, one in each corner. This vertical reinforcement is surrounded with wire fabric which serves in place of the usual hooping. The center column has the same length and reinforcement, but is 2 ft. square.

The concrete used in the floor and floor girders is a mixture of 1 part of Edison Portland cement, 4 parts of sand, and 2 parts of crushed stone which passed a 1½-in. mesh screen. In the tank wall and columns a 1:3:3 mixture of the same materials was used. All the concrete was mixed exceedingly wet and was literally poured into the forms.

The columns were poured first in the usual manner and allowed to set before the work proceeded further. When the floor and floor girders were poured, all concrete in these was placed in one operation. The work was done during summer weather, and it was felt that to place a layer of concrete on the decking, lay the reinforcement and then continue concreting would not secure the best results, owing to the detrimental effect of the sun on the thin layer of concrete first laid on the decking. In order to avoid this danger the reinforcement was all fixed in place, the wire cloth being stretched tight and supported on small blocks of wood tacked to the decking; then the concrete was laid, care being taken to work it through the meshes of the wire fabric and thoroughly fill the space between the reinforcement and the decking and also the girders below. The wetness of the mixture, the large percentage of sand used, and the rather large meshes of the wire cloth facilitated these operations and the results secured are very satisfactory. The floor reinforcement was carried up into the wall a short distance and the latter was constructed after the floor concrete was in place.

Special care was taken to secure a very dense concrete and after the forms had been removed the interior surface of the tank was given two coats of a very thin cement and water wash. This treatment was successful and no leaks have developed.

The tank supply, outlet and overflow pipes are carried up to the tank through a 3-in. lead pipe placed in the center of the center column. The necessary valves are placed in a cavity in the pedestal of this column and are readily accessible.



Water Tower at Katonah.

The tank was designed by Mr. Frederick J. Sterner, of New York, architect, and was built under the direction of Mr. Delancey A. Cameron, of New York.

Book Notes.

A valuable addition to text-books for college use is Dr. Adolf Thomälen's "Electrical Engineering," translated by Mr. George W. O. Howe. It takes the student from the simplest principles of physics to the complex conditions existing in dynamos when in operation. The explanations are based more on physics than mathematics, although the latter are used freely as convenient means for expressing physical relations. Many of the subjects likely to confuse the beginner, such as the operation of the stationary transformer, the parallel working of alternators, and the phase-swing of alternators, are explained with refreshing clearness. The treatment of the polyphase induction motor is unnecessarily complicated, but that of the single-phase motor is better. The book does not explain the details of the design of motors and dynamos but confines its explanations to such elements of construction as are required to understand the application of the principles which are under consideration. It is not a "popular" book, but a substantial, scholarly work. (New York: Longmans, Green & Co., $4.20).

Now that inland navigation is attracting so much attention the "Report of Examination of Ohio River," just issued as one of the documents of the House of Representatives, is certain to receive study, which it well merits as a most important, authoritative discussion of the improvement of the river. Three years ago the House made a special appropriation for a thorough examination of methods of canalizing the Ohio so as to secure depths of 6 and 9 ft. This study was entrusted to a special board, consisting of Colonels Lockwood, Ruffner and Sears and Majors Zinn and Sibert, of the Corps of Engineers, with Capt. Burgess as recorder. The report shows how thorough their investigations were. When it was completed, it was referred to the Board of Engineers for Rivers and Harbors for review. The latter differs on a few minor points of opinion, but recommends without qualification the improvements suggested. These provide for a 9-ft. stage by the construction of 54 locks and dams at an estimated cost of $63,731,488. The annual maintenance charges, including dredging, are estimated at about a million dollars. The report gives information concerning the character of the river, the various improvements in it up to the present time, the nature and extent of the shipping on it, and an estimate of the probable shipping if the improvements suggested are carried out. The introduction by General Mackenzie, Chief of Engineers, U. S. A., is particularly instructive. In it he points out clearly that the conclusions expressed in the report are based on a conjectural future commerce, rather than any that is now in sight. It is assumed that commerce will always seek the route which it finds cheapest, cost and convenience considered, that by the method of improvement suggested the cost and convenience of commerce up and down the valley can be made less than by any other method of transportation, and that under such conditions the traffic will surely seek the river. General Mackenzie agrees that the Board seems justified in reaching its conclusions, but he points out that Congress has never yet sanctioned a project of such extent upon considerations of this character. He also expresses in a most decided manner his opinion that the only correct way to improve the river is by canalization along the lines suggested in the report, and he strongly opposes the suggestion of attempting any open-channel improvements. The reason for this is that by canalization, currents are greatly reduced and upstream navigation is made easy.

The appearance of the second volume of Prof. Robert C. H. Heck's "Steam Engine and Other Steam Motors" will be welcomed by those who recall the first volume of this painstaking and scientific work, which was reviewed in this journal on Dec. 9, 1905. The first volume contained many theoretical discussions, with all of which probably no experienced student of the subject will wholly agree. The present volume relates to the actual engine and its performance, and is profusely illustrated from American sources; it is something of a pity that the author did not describe some of the important distinctively European details of design, like rocking cam lever valve-gear and the use of governors acting through a power relay, as these types are proving highly satisfactory. In the first portion of the volume the author discusses the main features of an engine, the frame, cylinder, reciprocating parts and rotating parts, dealing first with the general requirements and then explaining and criticising different methods of meeting them. The next section contains descriptions of valves and valve gears and graphical analyses of their action. The third section, on the action of governors, is probably the most complete treatise on the subject yet written, so far as the American types of such mechanisms are concerned. The action of inertia governors presents one of the most complicated dynamic problems the engineer has to solve, and the author's method has the merit of clearness and systematic procedure. The next section is on the interpretation of indicator diagrams and this is followed by a much condensed section on the steam turbine, which will doubtless be elaborated in subsequent editions of the book. The volume closes with a tabulation of the basic results of

American, British and German engine tests; the labor spent in the reduction of the test figures to a uniform form must have been very great, but the information will prove of so much value to engineers that the work will be widely appreciated. (New York: D. Van Nostrand Co., $5.).

One of the most fascinating fields of applied physics at the present time is that of telephonic communication without metallic conductors. Our battleship cruising fleet is now testing one system for which a great deal is claimed, and other systems have been tried with enough success to indicate that those who put their faith in the practicability of such communication have considerable justification for their high hopes. Those who wish to obtain a good knowledge of the subject will find the information well presented in Dr. James Erskine Murray's translation of Mr. Ernst Ruhmer's "Wireless Telephony in Theory and Practice." The book outlines the theories and apparatus of Bell, Tainter, Simon, Hayes, Duddell, Lodge, Majorana, Lecher, Peuckert, Thomson and others whose researches have contributed to the sum total of our knowledge useful in making wireless telephony practicable. The subject is one of great complexity at the present time, and the scientific principles and experimental apparatus throwing light on what is practicable and what is not are many and varied. Probably some of them are not given in this book and probably there are errors of a historical nature for which the limited printed information on this kind of telephony is responsible, but these are minor considerations and in no way detract from the marked merit of this timely volume. (New York: D. Van Nostrand Co., $3.50).

Letters to the Editor.

THE WATERBURY STREAM POLLUTION LITIGATION.

SIR: In recent issues of The Engineering Record you have referred to Massachusetts decisions regarding stream pollution, but I have seen no reference to the decision rendered some months ago by the Connecticut Supreme Court of Errors in the case of Platt Bros. & Co. against the city of Waterbury. These legal decisions are so important to engineers engaged in municipal work and the Waterbury case is such an old and well-known one, that I have no hesitation in bringing the latest aspect of it to your attention. The cause of the suit is the familiar one where an owner of riparian land claims damages resulting from the introduction of sewage by a city into a stream above his property on which the sewage sludge accumulates.

The plaintiff in the case owns property on the Naugatuck River, 2 miles below the city, and the water of that stream is used in its mills. The city constructed a sewer system in 1884 which discharged into the river 2 miles above the mills, causing the company so much trouble that in 1891 it brought an action against the city for damages and an injunction. The litigation dragged along until late in 1898, when damages to the amount of $500 were assessed against the city and an injunction was granted ordering the city to cease discharging sewage into the stream after Dec. 1, 1902. In March of that year the company again brought an action against the city, claiming damages for the pollution of the water from the date of the former action up to the time of the second suit. In the lower court it was decided that the company was entitled to such damages for a period of six years prior to the date of the complaint, and the city appealed from this decision. It is the decision on this appeal to which your attention is called.

The opinion was delivered by Judge Hamersley. He rules that the discharge of sewage into the stream in such a way that it is carried to and deposited on the company's land, there producing offensive odors, is an actionable wrong and the offense is a public nuisance. Such a wrong causes a legal injury from which damages necessarily result, although the company failed to prove that it had suffered any specific damages. Every day's continuance of acts causing such injury renders the city liable to a suit for the injuries resulting from them, according to Judge Hamersley, and the fact that the city's charter authorizes it to construct the sewerage system and acquire by eminent domain so much of the company's property as may be necessary in connection with the municipal sewering operations, is no defense to the company's right to recover specific damage caused by the nuisance on its land, when none of its property has been condemned for this public use. Although a prior judgment for damages from this cause may have been awarded, a continuation of the acts by the city may be made the ground for another suit, which cannot be avoided by subsequent proceedings for the condemnation of the company's property. The court has therefore approved the award by the lower court of damages in the amount of $15,000 against the city for the second period during which the nuisance existed.

The most interesting feature of the decision to me is the clear distinction made by Judge Hamersley between what is legal and what is illegal in connection with the discharge of sewage into the river. The construction of the Waterbury sewers in 1884, in accordance with the terms of its charter, was lawful and their construction so as to empty sewage into the river gave the company no cause of action. The sewers could be used for that purpose without an invasion of the company's rights and without damage to its property. But when the city discharged sewage into the river in such quantities and in such manner that it was carried without much change to the company's premises 2 miles below, there producing a public nuisance to the company's special damage, the city did not make a lawful use, but a misuse, according to Judge Hamersley, of its sewerage system. Each day such an unlawful act was repeated the company suffered a fresh invasion of its legal rights. It seems to me that this statement clears away much of the confusion that exists concerning the right to discharge sewage into streams, and, as I have never before seen the distinction made so clearly, I take the liberty of calling the decision to your attention.

WATERBURY.

BURNING ASHES.

SIR: The information furnished on page 252 of your paper of Feb. 29 ought to stop the silly talk that is going around concerning the alleged use of some chemical dope which renders ashes useful as a fuel. It is evident that the Board of Education in your city has come to a proper appreciation of that human frailty which doctors recognize when they prescribe inert powders as medicine for a patient who cannot be made to live as he should unless he is given to understand that he must take drugs to get back into condition. If he thinks his case is bad enough for pills and powders, it is generally possible to make him eat and sleep as he should, but without these things to be taken every little while he is unwilling to pay any attention to the really important part of the advice given him.

In the same way, the Board of Education has evidently determined to stop the waste of good coal, even if it is necessary to indulge in a little quackery to do so. It is manifest to those who are acquainted with the general average of the men engaged as janitors of schools that many of them care very little about running their boiler furnaces with the maximum economy, particularly when they must use unbroken anthracite. The only way such a grade of coal can be used economically is to screen out the unburned coal from the ashes and use it again. While some janitors will do this in a half-hearted way, some will absolutely neglect to do so. It is useless to try to enforce strict rules over men who have strong political influence and consider it beneath their dignity to sift ashes. On the other hand, the salt and oxalic acid dope used as described in your note a fortnight ago answers the same purpose as screening, although somewhat more expensive. It seems to me to be a pretty shrewd way of accomplishing a desirable end by means of a little harmless incantation that injures nobody.

Yours truly,

Boston, March 3. JACKSON BENNETT.

THE INLAND WATERWAYS REPORT.

SIR: Those of us who are interested in the possibilities of irrigation and flood prevention by national help in one way or another will hardly feel in accord with one feature of your remarks on the report of the Inland Waterways Commission, printed last week. You seem to fear that the joining together of river improvements, irrigation undertakings, flood preventive measures and all the other features of utilization of water resources will be dangerous mainly to the rational continuation of river and harbor work. Ever since such a proposal was made more than a year ago, I have lost no opportunity of talking it over with others engaged in Western enterprises, and the opinion out there is that the irrigation enterprises now going forward at a grand pace would be the chief sufferers if a single commission were to be put in charge of the entire great field of endeavor advocated by the report in question. Those who know all the difficulties that exist in securing appropriations for good river and harbor improvements and in preventing appropriations for useless work, will feel deep regret at any action coupling the present reclamation work with river and harbor improvements. Congress may like the idea of joining the two on account of the additional opportunities the combination will afford for log-rolling in the committee rooms, but those of us who like the way the Reclamation Act has worked and admire the manner in which operations under it have been conducted, do not wish it to be repealed, as it must be if irrigation works and river and harbor improvements are to be joined closely.

There is another reason why we do not like the proposed association of all branches of national hydraulic undertakings. We believe that only a beginning has been made in the investigation of scientific irrigation and drainage. We wish to see this work carried forward, as at present, by the harmonious action of federal and state organizations. We wish to have the work of the Forest Service continued and extended so that we shall know more about the relations between stream-flow and forests. The only trouble about the research of this nature now in progress is that there is not enough of it, but our Western Congressmen appreciate its importance and stand together as a unit in asking for appropriations for the purpose. If all hydraulic work is bunched together under a single commission, we can no longer exert the same influence on appropriations that we do now, but must dicker with Congressmen from the seaboard whereby they will gain appropriations for harbor improvement in return for their support for our own needs. When viewed in this way, the proposed union of all the hydraulic engineering undertakings of the government, while a theoretical simplification, is introducing actual complications wholly out of proportion to any gain to be derived from such a procedure.

WESTERNER.

REPORT OF THE ROYAL COMMISSION ON THE CAUSE OF THE COLLAPSE OF THE QUEBEC BRIDGE.

HENRY HOLGATE, J. G. G. KERRY, JOHN GALBRAITH, COMMISSIONERS.

The Royal Commission appointed by Commission dated Aug. 31, 1907, to inquire into the cause of the collapse of the Quebec bridge, begs to present its report as follows:

The members of the Commission were appointed on Aug. 30, 1907, the day following the accident, two of them proceeding to Quebec the same day, the third member arriving there on Sept. 4. The formal Commission was received on Sept. 9. The taking of evidence at Quebec was commenced on the afternoon of Sept. 9 and continued until Sept. 24. On Sept. 25 the Commission went to Ottawa and took evidence on Sept. 26 and Sept. 27. An adjournment was taken for the week ending Oct. 5. On Oct. 7 the Commission reassembled in Quebec and engaged in further examination of the wrecked structure and in study of the plans and documents. On Oct. 14 the Commission met in New York and commenced the first examination of Mr. Theodore Cooper, Consulting Engineer of the Quebec Bridge Co., which continued until Oct. 22. From Oct. 23 until Nov. 22 the Commission was engaged in the taking of evidence and the collection of information in Phoenixville and Philadelphia. During this period two members of the Commission visited the works of the Central Iron & Steel Co. at Harrisburg, Pa., and other steel and bridge works which had no direct connection with the manufacture of the Quebec bridge were inspected. A second visit was paid to Quebec from Nov. 28 to Dec. 3, and on Dec. 3 one member of the Commission visited New York to further examine Mr. Cooper, returning Dec. 8. On Jan. 14 two members of the Commission went to Phoenixville in order to make certain tests, returning on Jan. 23. Since Nov. 23, with the exceptions above mentioned, the time of the Commissioners has been spent in Montreal in examination and discussion of evidence and in preparing this report.

We understand that the Commission instructs us to determine to the best of our ability the cause of the collapse of the Quebec bridge and to thoroughly investigate any matters appertaining thereto which might enable us to explain that cause. We do not think that either the general design of the Quebec bridge, the methods of financing the enterprise, the payments of money that have been made to or by the company or in its interest, or the obligations that the company has undertaken under various contracts and agreements have direct connection with the fall of the bridge. In the course of our investigations we have secured a large amount of general information on these and other matters not directly pertinent to the object of the inquiry, some of which has been introduced into this report so that the history of the undertaking might be more readily followed. We have not considered the scope of our inquiry limited concerning any matters which, in our judgment, related to the collapse of the bridge.

Some of our various inquiries have yielded negative results, but these are dealt with at some length in the report to make it clear that the subjects of these inquiries have not been overlooked.

In carrying out our instructions we have made the following investigations:

(a) A study of the history of the Quebec Bridge & Ry. Co., the evidence at our disposal being copies of the various public acts concerning it, the minutes of the directors' meetings, the reports of its officials, its annual reports, its correspondence and copies of the agreements and contracts that it has made.

(b) A perusal of the entire correspondence on file in the offices of the Quebec Bridge & Ry. Co., the Phoenix Bridge Co. and Mr. Theodore Cooper.

(c) A study of the working organizations of the Quebec Bridge & Ry. Co., the Phoenix Bridge Co. and the Phoenix Iron Co. This involved the hearing of a number of witnesses under oath and the examination of the various documents produced by these witnesses on direction of the Commission and filed as exhibits.

(d) A personal inspection of the furnaces and rolling mills by which most of the metal that was used in the bridge was produced. The testing equipment at each of the works was examined and the file of the records of tests made by the inspectors during production was gone over.

(e) A study of the methods used in the fabrication, transportation and erection of the bridge. This consisted of inspection of the shops of the Phoenix Iron Co., in which all the metal was fabricated, and an examination of the plans, records, correspondence and photographs on file in the office of the Phoenix Bridge Co. The fabricated material for the north half of the bridge was also inspected and check measurements were taken to determine certain questions of workmanship.

(f) A study of the errors in workmanship detected by the several inspectors during the progress of the work, the evidence available being the record books kept by the shop inspectors for the Phoenix Bridge Co. and for the Quebec Bridge & Ry. Co., the "field corrections" sent by the Phoenix Bridge Co.'s resident engineer to the erection department of that company and the weekly reports made by the inspector of erection for the Quebec Bridge & Ry. Co. to the consulting engineer.

(g) An inquiry into the history of the erection of the bridge. The inquiry was made by obtaining direct evidence from witnesses under oath and by tracing out through records and correspondence the details of all the major difficulties that had occurred in the course of construction.

(h) An endeavor to obtain from eye-witnesses of the disaster all details concerning it. Some twenty-five witnesses were examined for this purpose.

(i) An examination of the meteorological records for the day of the accident and for some time previous. The records of the Observatory at Quebec and those kept by the Phoenix Bridge Co.'s staff were available for this purpose.

(j) A personal examination of the fallen structure made at different times and occupying several days, together with such surveys, check measurements and photographs as were considered necessary.

(k) A study of the methods adopted in the design of the bridge. This study required an inspection of the drafting office of the Phoenix Bridge Co. and an examination of the mass of preliminary and final designs on file there. The sworn statements of all the senior engineers formed an important part of the inquiry.

(l) A checking of the stress sheets prepared in the offices of the Phoenix Bridge Co. by comparison with the results obtained by Mr. C. C. Schneider, consulting engineer, who was employed subsequent to the disaster by the Department of Railways and Canals to report to it upon the design of the bridge.

(m) A comparison of the organization and specifications used for the Quebec bridge with those used for existing great cantilever bridges on this continent.

(n) A replotting of the records of tests made on full-sized compression members and a comparison of the design for the principal compression chords of the Quebec bridge with similar designs for other great cantilevers. In this connection special tests were made both by the Phoenix Bridge Co. and by the Commission, the details of which are given.

(o) A study of the theory of compression members, standard books, transactions of technical societies and professional journals being consulted. The purpose of this part of the inquiry was to determine how thoroughly the designers of the bridge availed themselves of the professional knowledge at their disposal.

Your Commissioners desire to acknowledge the hearty co-operation throughout the inquiry of all officials of the companies directly concerned. Messrs. Cooper, Szlapka, Deans and Hoare especially have, in our judgment, made every effort in their power to assist us to establish the facts and have not attempted to spare themselves.

Some clearly contradictory statements are to be found in the evidence given in the early days of the inquiry by certain witnesses on whom the burden of the disaster fell. These statements may be attributed to the nervous tension under which the witnesses were laboring at the time.

Your Commissioners find:

(a) The collapse of the Quebec bridge resulted from the failure of the lower chords in the anchor-arm near the main pier. The failure of these chords was due to their defective design.

(b) The stresses that caused the failure were not due to abnormal weather conditions or accident, but were such as might be expected in the regular course of erection.

(c) The design of the chords that failed was made by Mr. P. L. Szlapka, the designing engineer of the Phoenix Bridge Co.

(d) This design was examined and officially approved by Mr. Theodore Cooper, consulting engineer of the Quebec Bridge & Ry. Co.

(e) The failure cannot be attributed directly to any cause other than errors in judgment on the part of these two engineers.

(f) These errors of judgment cannot be attributed either to lack of common professional knowledge, to neglect of duty or to a desire to economize. The ability of the two engineers was tried in one of the most difficult professional problems of the day and proved to be insufficient for the task.

(g) We do not consider that the specifications for the work were satisfactory or sufficient, the unit-stresses in particular being higher than any established by past practice. The specifications were accepted without protest by all interested.

(h) A grave error was made in assuming the dead load for the calculations at too low a value and not afterward revising this assumption. This error was of sufficient magnitude to have required the condemnation of the bridge even if the details of the lower chords had been of sufficient strength because, if the bridge had been completed as designed, the actual stresses would have been considerably greater than those permitted by the specifications. This erroneous assumption was made by Mr. Szlapka and accepted by Mr. Cooper and tended to hasten the disaster.

(i) We do not believe that the fall of the bridge could have been prevented by any action that might have been taken after Aug. 27, 1907. Any effort to brace or take down the structure would have been impracticable owing to the manifest risk of human life involved.

(j) The loss of life on Aug. 29, 1907, might have been prevented by the exercise of better judgment on the part of those in responsible charge of the work for the Quebec Bridge & Ry. Co. and for the Phoenix Bridge Co.

(k) The failure on the part of the Quebec Bridge & Ry. Co. to appoint an experienced bridge engineer to the position of chief engineer was a mistake. This resulted in a loose and inefficient supervision of all parts of the work on the part of the Quebec Bridge & Ry. Co.

(l) The work done by the Phoenix Bridge Co. in making the detailed drawings and in planning and carrying out the erection and by the Phoenix Iron Co. in fabricating the material was good and the steel used was of good quality. The serious defects were fundamental errors in design.

(m) No one connected with the general designing fully appreciated the magnitude of the work nor the insufficiency of the data upon which they were depending. The special experimental studies and investigations that were required to confirm the judgment of the designers were not made.

(n) The professional knowledge of the present day concerning the action of steel columns under load is not sufficient to enable engineers to economically design such structures as the Quebec bridge. A bridge of the adopted span that will unquestionably be safe can be built, but in the present state of professional knowledge a considerably larger amount of metal would have to be used than might be required if our knowledge were more exact.

(o) The professional record of Mr. Cooper was such that his selection for the authoritative position that he occupied was warranted and the complete confidence that was placed in his judgment by the officials of the Dominion Government, the Quebec Bridge & Ry. Co. and the Phoenix Bridge Co. was deserved.

Owing to the necessity of having the evidence taken in the United States sworn to before a British Consul, written questions were submitted to each witness examined in the United States and written answers were returned after an interval of some days.

The Commission is greatly indebted to the following gentlemen, who have most courteously furnished information: Mr. Charles Macdonald, formerly chief engineer of the Union Bridge Co., contractors for the superstructure of the Memphis cantilever bridge; Mr. H. W. Hodge, of Messrs. Boller & Hodge, engineers of the Monongahela cantilever bridge; Mr. Ralph Modjeski, of Messrs. Noble & Modjeski, engineers of the Thebes cantilever bridge; Messrs. Ingersoll and Seaman, of the Department of Bridges of the City of New York, and Messrs. Reynders and Kunz, of the Pennsylvania Steel Co., respectively engineers and contractors for the superstructure of the Blackwell's Island cantilever bridge.

We are also indebted for professional advice and assistance to Professor Mansfield Merriman, Professor W. C. Kernot, Professor W. H. Burr, Professor Edgar Marburg, Professor H. M. MacKay, Professor G. F. Swain and Messrs. W. R. Webster, T. K. Thomson and E. W. Stern, consulting engineers.

The technical investigations have been by far the most arduous and difficult part of our inquiry and it is questionable whether they could have been brought to any conclusion without the assistance that these men of expert training and experience have so freely given.

We have set forth the facts which have convinced us of the soundness of our findings in the accompanying appendices, each of which is an independent discussion dealing at length with some one phase of our inquiry. The subjects of these appendices are as follows:

1. The evidence given before the Commission of Inquiry.
2. The exhibits filed with the Commission of Inquiry.
3. The history of the Quebec Bridge & Ry. Co. up to the end of the month of August, 1903.
4. The Phoenix Bridge Co.
5. The effect of financial limitations upon the design of the bridge and a discussion of the evidence relating to this.
6. The history of the development of the specifications and a discussion of the evidence relating to it.
7. A description of the organization and staffs maintained by the different corporations interested in the erection of the bridge.
8. A history of the development of the plans and of the methods followed in the designing offices.
9. Material shop work and inspection.
10. Transportation and erection.
11. A discussion of the difficulties that arose during erection and of the events at the time of the collapse of the structure.
12. A description of the fallen structure.
13. An enumeration of the various full-sized column

tests that have been made in America accompanied by diagrams showing the results of these tests.

14. A comparison of the stresses in the several members of the main trusses computed from the bridge as finally designed, with the stresses authorized by the specifications. This comparison was made by Mr. C. C. Schneider, consulting engineer, and is embodied in his report to the Department of Railways and Canals.

15. A description of the various experimental researches that have been made in connection with the building of the Quebec bridge and during this inquiry.

16. A discussion of the theory of built-up compression members.

17. A comparison of the design for certain chords of the Quebec bridge with those for similar members of other great cantilever bridges illustrated with outline drawings of the bridges and copies of the shop drawings of the chords.

18. A critical discussion of certain parts of the specifications.

19. Miscellaneous information.

All of which is respectfully submitted.

Henry Holgate, Chairman.
J. G. G. Kerry,
John Galbraith.

APPENDIX 1—THE EVIDENCE BEFORE THE COMMISSION.

The testimony taken by the Commission is so voluminous that it will make a large volume when printed, and only abstracts of those portions relating particularly to the statements in the Commission's report will be given here. Before presenting them, however, a list of articles in this journal relating to the bridge is given, as a reference to them will make clear all features of the design, method of erection, and the nature of the collapse.

July 27, 1901. A description of the construction of the piers.

March 4, 1905. General description of the design of the superstructure and the methods of erection.

April 1, 1905. Notes on the methods of design, the shore piers, anchorages, lateral systems and sway bracing.

April 8, 1905. Notes on the main vertical posts, shoes and pedestals, intermediate vertical posts, bottom chords, and eyebars.

Sept. 16, 1905. A statement of the progress of erection and a description of the main pedestals and the members meeting there.

June 23, 1906. An account of the erection of the south anchor arm of the bridge.

Sept. 8, 1906. The steel falsework used in the erection of the anchor arm.

Sept. 15, 1906. The method of making the camber adjustments.

Sept. 22, 1906. The method of storing and handling members during the erection of the bridge.

Dec. 1 1906. The materials and maximum stresses in the anchor arms.

Dec. 15, 1906. The fabrication of the members in the shop.

Dec. 29, 1906. The adjustable connection of the anchor-arm lateral system.

Jan. 12, 1907. The anchor pier towers.

Jan. 19, 1907. Erection attachments for the bottom chords and vertical posts.

Jan. 26, 1907. Erection of the main vertical posts.

Feb. 9, 1907. The method of handling and connecting eye-bars.

Feb. 23, 1907. The traveler for the erection of the anchor and cantilever arms.

March 2, 1907. Special equipment used in erection of the anchor arm.

June 22, 1907. Details of the vertical bent on the main pier and the bolsters.

July 6, 1907. Details of the main pedestal.

July 13, 1907. Details of the upper part of the center posts.

July 20, 1907. Details of vertical post 4, adjacent to the main post.

July 27, 1907. Details of an intermediate post.

Aug. 3, 1907. Details of diagonal members.

Aug. 10, 1907. Details of the lower chords of the anchor arm.

Aug. 17, 1907. Details of the floor system.

Aug. 24, 1907. Details of the transverse bracing.

Sept. 7, 1907. Current News Supplement. A detailed statement of the condition of the wreckage, with a summary of the reports of the collapse made by eye-witnesses.

Sept. 14, 1907. Current News Supplement. A collection of views of the wrecked structure.

Sept. 21, 1907. The suspended falsework of the cantilever arm.

Sept. 28, 1907. A description of the methods followed in erecting the cantilever arm.

Testimony of John Sterling Deans.

Mr. Deans testified that he was chief engineer of the Phœnix Bridge Co. and first consulted with Mr. E. A. Hoare, chief engineer of the Quebec Bridge Co., concerning the Quebec bridge in the summer of 1897, during a convention of the American Society of Civil Engineers in Quebec. Shortly afterward he received from Mr. Hoare a profile of the proposed site and other general information. Preliminary studies for the structure were made by the Phœnix Bridge Co. and were filed with the Department of Railways and Canals by the Quebec Bridge Co. in advance of the submission of competitive tenders. At the time tenders were asked, about a year later, bidders had free scope in the matter of design, length of anchor arm and other features, and were asked to bid not only on a cantilever span, but also on a suspension design. As a matter of fact the Phœnix tender did not agree exactly with the above preliminary study.

It was understood that economy of design was of importance, but not of first importance and not to be secured at the expense of any requirement of the specification or of obtaining the most capable contractor for the work.

Mr. Cooper reported favorably on the plan and bid submitted by the Phœnix Bridge Co. on March 1, 1899, and the contract was awarded to the company on his recommendation.

At Mr. Cooper's request Mr. Szlapka had interviews with him at which Mr. Cooper stated that it was proposed to increase the span and amend the specifications. The Phœnix Bridge Co. had nothing to do with the determination of these questions.

Ample time was given for the study and preparation of plans. The actual weight of the suspended span did overrun that assumed in the original calculations. The estimated weight was necessarily approximate.

The final arrangements under the contract were made on Feb. 22, 1904, which permitted the Phœnix Bridge Co. to proceed freely with its work.

Work was done in many instances including anchor-arm chords and other members upon receipt of plans approved by Mr. Cooper and before the plans were actually approved by the Government, as Mr. Cooper's approval was final as far as we were concerned. No changes were ever made by the Government on any plans approved by Mr. Cooper.

The contract between the Phœnix Bridge Co. and the Quebec Bridge Co. provided for payment at prices per pound of material erected complete. There was no limit placed upon the former company as to the amount of money the bridge should not exceed in cost, or was any sum mentioned that it would not exceed. No financial considerations governed the Phœnix Bridge Co. in the design of the structure. The consulting engineer effected economy in cost by changing the specifications, and these changes lowered the efficiency of the bridge. In details not expressly covered by the specifications he also exercised economy. He endeavored to reach an economical design, and the Phœnix company did not think he carried this so far as to imperil the safety of the structure.

Changes in unit stresses were made by Mr. Cooper and were not submitted to the Phœnix company for approval. Mr. Cooper merely talked the matter over with Mr. Szlapka as a brother engineer, but not, however, for the purpose of getting the wishes of the Phœnix Bridge Co. He then reached a decision of which the company was notified and upon which it acted. The changes in unit stresses for compression members carried them out of the field of past experience in bridge construction and detailing and did not follow usual practice.

The Phœnix company took all the time considered necessary for the study and preparation of plans, and Mr. Deans believed Mr. Cooper's office also took all the time that they considered necessary. The examination of details and plans by Mr. Cooper's office was conscientiously and carefully done. Discussions often arose, but Mr. Cooper's decisions always prevailed. All plans were approved by the consulting engineer.

In a few instances and late in the work, plans were sent to the shops for preliminary work before the actual approval by the consulting engineer, so that the company would be prepared to carry on the work promptly. This was done only in the case of plans of which the design and detail had already been established and approved by the consulting engineer. The company took the risk of possible alterations by him. But in no instance was a single member of the bridge actually completed which was not in accordance with the final approved plans.

The design of the details of the lower chord was discussed with Mr. Cooper and his opinion was specifically obtained on the latticing and other details. Mr. Deans had no interview with Mr. Cooper on this subject, but instructed his designing engineer particularly to submit the question of size of latticing of chords to Mr. Cooper. Mr. Szlapka later reported that Mr. Cooper advised him that the lattice angles were correct as shown on the approved plans.

The Phœnix Bridge Co. maintained an independent inspection of the shop work done by the Phoenix Iron Co. Every error, however small, was noted, recorded in a book, and all these errors were corrected before the work left the shop.

Special precautions were taken to insure the safety of the bridge members during handling in transportation. The Phoenix Co. consulted with the Superintendent of Motive Power of the Pennsylvania R.R. Co. and devised with his representative special schemes of loading. All large and heavy pieces were the subject of special consideration with the transportation companies. All members were carefully inspected as to distortion and injury during transit, after the members arrived at bridge site and before they were erected in place. This inspection was by the representatives of both the Quebec Bridge & Railway Co. and the Phoenix Bridge Co. Only one member was injured in transit, being the shell frame of the south anchorage. One member was injured in handling at south storage yard, being chord 9 L of the anchor arm. One member was dropped in handling in the shops, slightly injuring it and one or two other smaller members. These members were thoroughly repaired under the direction and to the satisfaction of the inspectors.

In response to one of the questions Mr. Deans paid the following tribute to A. H. Birks, who lost his life at the time of the collapse:

"A statement of Mr. Birks' experience in no sense conveys a proper estimate of his ability, which was unusual for a man of his years. He was specially fitted by character and temperament for the work entrusted to him. His experience was as follows:

"On March 22, 1902, we received a letter from George F. Swain, professor of civil engineering at Massachusetts Institute of Technology, Boston, suggesting the name of A. H. Birks to us as a desirable man for our engineering department. He wrote as follows: 'I also have an exceedingly good man who graduated in architectural engineering and has been taking a post-graduate course with me. His name is A. H. Birks. Birks is a man of exceptional ability in this line and having taken all my work in structures is as well up in bridge work as building work. He has also had some experience, having worked one summer with a bridge company and one year in an architect's office, I believe. He is an exceptional man.'

"We gave Mr. Birks a position and he started to work in our drafting department and worked there for about six months. We soon found he had traits of character and ability that would fit him well for erection work, and he was transferred to the erection department Oct. 7, 1902.

"Between Oct. 7 and Nov. 8, 1902, he was in the field on erection of plate-girder spans, N. & W. Bridge, Circleville, O.; Dec. 1, 1902, to June 15, 1903, on Central R.R. of N. J. plate-girder bridges at Wheelers Lock, Parryville, and Glen Onoko and the Lehigh River bridge at Parryville which has through riveted spans; June 18 to Aug. 13, 1903, Southern Ry. bridges, Caswell, Tenn., Mascot, Tenn., Knoxville, Tenn., Alexandria, N. C., Wolf Creek, Tenn., Jefferson City, all plate-girder spans, and Tennessee River Bridge, Straw Plains, Tenn., 105 ft., a deck plate-girder structure. Feb. 11, 1904, and during the month he was Inspector on Southern Ry. bridges, James River Bridge, Lynchburg, Buffalo River Bridge, Rappahannock River Bridge, all through truss bridges. July 24 to Aug. 3, 1904, at Deepwater, French Broad River, Hot Springs, N. C., on a 264-ft. through pin span during the erection of the trusses. In March, 1905, at Jacksonville, Fla., examining the sites of two Atlantic Coast Line R.R. draw bridges, securing necessary information for preparing erection plans. In February, 1906, at New London, Conn., arranging the method of erecting the Jordan Cove Bridge. During the intervals not covered by the above, Mr. Birks was engaged on erection plans and details in the office at Phoenixville.

"When the Quebec erection was taken up early in 1904, Mr. Birks assisted in all the preliminary studies and continued on this work until the entire plan was fully developed and settled upon. Many of the features of this erection scheme, which worked out so successfully in practice, were due to Mr. Birks' peculiar ability in this line. His familiarity with every detail of the erection scheme and the behavior of the trusses during erection, his thorough technical training, his absolute reliability, decided us to appoint him resident engineer of the erection and he was sent to Quebec in September, 1904. He was on the work during the working season from that time until the date of the disaster, with the exception of the period during the erection of the main traveler, when Mr. C. W. Hudson was resident engineer.

"Mr. Birks was fearless and was able to climb over the entire structure. He had a lovable character and that about him which instantly demanded respect and confidence. He could have his orders carried out readily without friction. It would be difficult to find a man combining so many traits of mind and character which so eminently fitted him for the position of resident engineer of erection."

After the lower chords, including the details of shop and field supplies, were approved by the Consulting Engineer, the engineers of the Phoenix Bridge Co. carefully considered the action of the field splices during the connection of the trusses and the camber movement of splices while the members were receiving their full dead load. A special camber blocking was designed and placed on falsework under each panel point. This blocking was easily adjusted and free to move longitudinally. Special consideration was given to the bolting before the riveting of splices. Full instructions were prepared in advance of erection and incorporated in a book of instructions to the field force. The bolting was checked in person by the resident engineer and regular reports sent to Phoenixville. The action of the joints was noted and reported on printed forms as erection proceeded, by the resident engineer in charge of field instrument work. The action of the joints was also noted specially by the designing engineer and assistant engineer in charge of details during several visits to the bridge site. All of this was in addition to the regular erection supervision by the general foreman and his assistants. The splices were under the closest scrutiny at all times and they acted as expected in closing to complete contact. No report was received at Phoenixville advising of anything wrong in connection with any splice until Aug. 8, 1907, in a letter from Mr. Birks, dated Aug. 6, 1907. In this letter he advised that one of the inside ribs at bottom of splice chord 7L—8L, cantilever arm, was bent out of line and enclosed a sketch of a diaphragm to be riveted between the ribs to hold them in their position. This proposed diaphragm was sent to Mr. Cooper by Mr. McLure on the same date as it was sent to the Phoenix Co., but he did not approve it. Mr. Cooper never gave the company any instructions concerning the matter. In a letter dated Aug. 16 he desired before acting to get further information from his resident engineer, Mr. McLure. A letter from him on Aug. 21 indicated that he had not yet reached a decision and the matter was still in this unsettled state when the accident occurred. There were no joints in the anchor arm where a similar bend in the rib was noticed, they all lined up true and satisfactorily.

Chords 9L, anchor arm, and 9R and 8R, cantilever arm, were in perfect condition when they left Phoenixville.

The position of the wreckage indicated to Mr. Deans' mind that a compression member, a lower chord in the anchor arm of the downstream truss, failed first and, immediately following, the compression member directly opposite failed. The failure of these two compression members permitted the anchor arm to move two panels toward the river. The lower chord of the cantilever arm being relieved of support, forced the two shoes towards the shore and broke off a lower section of the main post. The downstream chord anchor arm failing first permitted the truss to drop vertically as well as horizontally and had a tendency to pull the higher parts of the superstructure downstream. The pinnacles at the top of main post pointed in this direction in the wreckage.

On Aug. 29, 1907, the Phoenix Bridge Co. first learned from a letter of Aug. 27 from Mr. Yenser that buckles were noticed in the webs of lower chord 9L of the anchor arm. Consultation then took place at Phoenixville between the engineers, shop officials and inspectors, and it was determined that the chord could not be bending from any excessive stress, as it was carrying only three-quarters of the working load for which it was designed and approved. The Phoenixville engineers then telephoned this conclusion to Mr. Yenser and Mr. Birks. During this conversation they notified the Phoenix Co. that a portion of the bends had been in the webs for a long time. That since writing on Aug. 27 they had carefully watched and repeatedly examined the chords and found there was no further movement, and that they had proceeded with the erection without waiting for advice from us. As this action agreed with the Phoenixville engineers' conclusion they were told they had acted wisely in not stopping the erection.

While a chord with bent webs, even though the bends are slight, is not capable of performing its functions as well as a perfectly straight member, the bends in chord 9L noted on Aug. 27, and of which the company learned on Aug. 29, were not such as to shake the absolute confidence of years which all had in the entire structure. If the Consulting Engineer then believed there was imminent danger and that all work should be stopped immediately, it was not necessary to inquire whether Mr. A. B. Milliken was at the site or not. Mr. Hoare had sent Mr. McLure to Mr. Cooper to report on the bends in chord 9L and to receive his advice. Mr. Hoare was in Quebec and any message to him would have stopped the work instantly, as was done on a previous occasion by direction of Mr. Cooper. The testimony of others shows that Mr. Cooper on Aug. 29 no doubt had no thought of imminent danger. "We all now see," Mr. Deans testified, "what no one dreamed of before, that the compression chords were beyond any scheme of protection on Aug. 29 and were failing under less than half the load for which they were designed and approved and were considered capable of sustaining without failure. While it is difficult, it is essential, in order to reach an accurate judgment, to keep in view the frame of mind every one was in before Aug. 29 regarding this structure and its strength and the respect and confidence all had in the engineers responsible for its design and detail."

The bridge was designed in its general features by the engineers of the Phoenix Bridge Co. The details of the bridge were worked out in connection with the Consulting Engineer, to agree with the modified specifications which he had prepared, and all plans and details were approved by the Consulting Engineer, Mr. Cooper.

The time for completion in the contract of June, 1903, was given as Dec. 31, 1906, and was fixed by the Quebec Bridge Co. The Phoenix Bridge Co. believed this time was too short and would not agree to be bound by it, and on the date the contract was executed letters passed between the two companies extending the time to Dec. 31, 1908. Mr. Cooper subsequently expressed his opinion in this connection, saying four or possibly five years would be required for the construction of the bridge, this long time being required because of the short working season for erection, and not because of other construction demands. As a matter of fact, the Phoenix Bridge Co. was unable to start on the work as early as had been expected because of the delay in the completion of the south approach to the bridge, and hence, notwithstanding due diligence on its part, the work could not have been completed for some time after Dec. 31, 1908. The Phoenix Bridge Co., when asked at the time of signing the contract and later, assured the Quebec Bridge Co. and the Government that it would use every effort to complete the bridge within the contract period, but no promise was made to do so.

In reply to one question Mr. Deans testified that he knew of no system of erection of a stiff frame which could be carried out without some form of a camber system. It was a mechanical necessity. This system had been used with success from the beginning of bridge construction, and in the Quebec Bridge was worked out in greater detail than ever before. A special camber blocking at each panel point enabled the erectors to keep the work in absolute control. As the dead load was applied and changes in anchor frame were taking place, the action of all joints was watched and reported and it was found that the truss was behaving exactly as expected and it continued to do so up to the time when all joints had a full and complete bearing.

Testimony of Theodore Cooper.

Mr. Cooper testified that about Feb. 25, 1899, he received a communication from the Quebec Bridge Co., asking if he was at liberty to take up the examination of their competitive plans, and he replied in the affirmative. The next occurrence was on March 23, when Messrs. Parent, Hoare and Barthe had a personal interview with him in New York. They gave him a brief account of what the plans were, of which Mr. Cooper had no previous knowledge, and asked him upon what terms he would undertake the examination and how much time it would probably require. He stated, with the slight knowledge he had of what they were describing, and assuming that they wished a relative report rather than a detailed critical report on all the numerous plans, that he thought it would require about three months' time, and he stated his fee for performing that service. They then asked him under what terms he would act as consulting engineer when the work was under construction, and Mr. Cooper stated his fee. They then asked if the inspection work was included in his services, and he distinctly stated it was not. They then asked him to give them an estimate of what the probable cost of inspection would be. He told them that, with the slight knowledge he had of the subject, his estimate would be very much in the line of a guess, but he assumed from the magnitude of the work and from what he supposed it would be that it would probably cost from $20,000 to $25,000 for the shop inspection. They did not accept any of his offers at that time, but Mr. Parent left him under the impression that the plans would be sent to him. His offer as consulting engineer was not acted upon.

At the present date and with the advantage of the several years of additional experience, he confirmed his original recommendation, both as to the type of the structure and as to the merits of the design submitted, under the same limitations that existed at that time as to the amount of funds apparently estimated for the construction. That he considered an important point, because the structure was apparently limited to the amount of funds they had in sight, as far as it was impressed on him. The impression was given him that this work was to be constructed by a private corporation, that the amount of money that they expected to have was a limited amount, and the question to be decided was the possibility of building the best bridge within the financial strength of the company. The question of the best possible bridge was not brought up at all.

Mr. Cooper received a letter appointing him consulting engineer to the Quebec Bridge Co. on May 6, 1900. In a supplementary report, with even date of his report upon the competitive plans, June 23, 1899, he stated in a general way that his examination of the competitive plans was based entirely upon the specifications and data furnished him by the Quebec Bridge Co. He thought that, before the construction of the work should be undertaken, a careful study should be made to see if a better bridge could not be had and whether a change of span was not desirable. On May 10, 1903, Mr. Parent informed him that the financial affairs were in such shape that the work could then be done. Mr. Cooper then took up again with the Phoenix Bridge Co. and with the chief engineer the necessary modification of the loads and stresses to suit a bridge of this magnitude. After considerable discussion between Mr. Szlapka, the designing engineer of the Phoenix Bridge Co., and Mr. Hoare and himself, it was found that nothing could be done in the way of changing the original specifications, except with the authority of the Deputy Minister of the Department of Railways and Canals. After considerable correspondence and discussion, and a personal visit to Ottawa, Mr. Cooper received on Aug. 23 a copy of an Order-in-Council, dated Aug. 15, certified by the clerk of the Privy Council, giving him, in a general statement, the authority to make modifications from time to time in the specifications and the proposed loadings, subject to certain provisos and "provided the efficiency of the structure be fully maintained up to that originally defined in the original specifications attached to the company's contract."

Mr. Cooper could not recall having been consulted in any manner on the framing of the contract. He considered that the Order-in-Council of Aug. 15, 1903, gave him, as consulting engineer for the Quebec Bridge Co., full and absolute authority to amend the specifications and to order such alterations in the construction plans as seemed best in his judgment, under the restriction that the efficiency of the structure should not be in any way reduced from that originally proposed and subject to the provisos previously referred to. Every change of any importance made by Mr. Cooper, certainly all those in the specifications, were referred to the chief engineer, Mr. Hoare, and supposedly through him to the department.

As an experienced engineer of many years' standing, Mr. Cooper recognized that the original specification of the Quebec Bridge Co. was what he would call a "scissored" one, that it was not drawn upon any theory by any person having the importance of this bridge structure in his mind. Although a specification for a Canadian bridge, there was no recognition of the snow weight that must at times come upon this structure. The requirements for the wind strain were those practically imposed upon the Forth Bridge, against the protest of the chief engineers of that bridge, Messrs. Baker and Fowler. The train load and train requirements were not as great as he thought they should be in the present state of transportation. He saw that a large amount of the material in this bridge was going to be devoted to giving it horizontal strength against an imaginary and an impossible wind, material that could be much more favorably placed to give the bridge vertical strength under higher train loading.

He therefore corrected the specifications to provide for a less wind strain than that originally required, with a greater vertical loading than that at first required. Being impressed with the necessity of restraining the weight of the structure under these new loadings and changes of loads so that it would not exceed the original estimated weight contained in the contract, he made modifications in the unit strains to be employed upon the various members, with the view of keeping the final weight within the limitations and yet obtain more harmony in the relative strength of the different parts of the structure.

Previous to taking up the consideration of the new loadings the 210-ft. spans making the approaches on each side had been constructed. On examining the plans, when submitted to him, Mr. Cooper found that the floor system was excessively heavy. He immediately wrote to Mr. Hoare, the chief engineer of the Quebec Bridge Co., that he found the floor system on these 210-ft. spans unnecessarily heavy; that they exceeded by 18 to 20 per cent. the best requirements of the Pennsylvania Railroad and all first-class railroads in the United States; that he understood that directions had been given to build these approach spans according to the official specifications of the Department of Railways and Canals of Canada. He wrote Mr. Hoare as follows: "While it is a matter of not much importance for these particular spans, if this is to be taken as a precedent for the main spans it will add considerably to the weight." He afterwards explained that for every extra pound put in the floor system from four to five pounds extra metal would be required in the trusses to carry it, and that this excessive requirement would render it impossible to build the structure within the limitation of the financial ability of the company, and that he did not consider it would in any way detract from the perfectly safe and satisfactory building of the bridge to lower the requirements to those accepted by the first-class railroads throughout the United States.

These alterations were discussed with the designing engineer of the Phoenix Bridge Go. This, however, was not for the purpose of getting at their wishes, but to get the benefit of the views of Mr. Szlapka, a brother bridge engineer, upon the suggestions that witness was making.

The Phoenix Bridge Co. practically had the contract for the construction of this bridge several years before they commenced the preparation of the plans. Mr. Cooper urged them at an early date to prepare their studies and plans as far as possible for the accepted 1,800-ft. span, for which no plans had yet been prepared, stating that in an important work like this very cautious and very careful consideration would be required in each and every individual detail of the structure, and that this should be done before the rush of construction would come upon them. They gave this no attention and practically made no steps towards preparing the plans, Mr. Cooper testified, until they had completed their financial arrangements and had executed their present contract, dated June 19, 1903.

There was not time enough given, in Mr. Cooper's opinion, to the careful study and preparation of the drawings and plans of this structure, free from the rush and push of its practical execution. The time stated in this contract for the completion of the work, as verbally given to Mr. Cooper by Mr. Deans at the time, was three years. Mr. Cooper protested against that and stated it was an absolute impossibility to construct that bridge in three years; that under the most favorable circumstances, without considering any contingencies, four years, at least, would be needed, and, in his judgment, five, at least, should have been asked for. He told Mr. Deans at that time that this meant rush and hurry and the impossibility of giving thoughtful and careful consideration to every step before undertaking the work in the shop. The urgency and demand of the manufacturing side of this problem, in his opinion, outweighed and burdened the technical and thoughtful consideration of all the plans.

For the checking of the strain sheets and detail plans prepared by the Phoenix Bridge Co. Mr. Cooper relied on his own office organization absolutely. This organization was maintained at his own expense, and he testified that it was not sufficient for the purpose, considering the other duties which were imposed upon him improperly. He considered this work properly part of the duties of the consulting engineer.

It was necessary to order alterations in the plans prepared by the Phoenix Bridge Co. Numerous comparatively minor alterations were frequently called for when the detail plans did not fully come up to the requirements. The most important alteration, however, was that of the long eyebar chord of the anchor arm. It was about June 1, 1904, that the Phoenix Bridge Co. submitted their plan and arrangements for the top chord and diagonals of the anchor arm. After careful personal examination Mr. Cooper declined to approve it, as having violated the requirements that he had stated in a personal conference with the engineers and proprietors of the Phoenix Bridge Co. he should demand. At that conference he stated that he would accept no bars exceeding 2 in. in thickness unless it was an absolute necessity to use a greater thickness. His experience had proved to his satisfaction that when that thickness was exceeded satisfactory bars could not be obtained. In this plan submitted for the top chord they had used bars 2½ in. in thickness and other prohibitory thicknesses, and they had arranged the bars at angles which were, to his mind, thoroughly unsatisfactory, and he called for a new design.

Mr. Szlapka, in a personal interview, protested that it could not be made better; that he had had his best men on it for two months, and he could see no change that could be made in it that would come nearer to his requirements than this plan. Mr. Cooper finally was compelled personally, although it was work he had not done for twenty years, to redesign the whole system. It was a very arduous and trying work, and when he was through he was thoroughly exhausted. He gave them a copy of his design and stated that it was not the best that could be done, but that it was the best that he could do, and he hoped now they would take the matter up from the point of view of the changes he had made and still further improve it in certain details which he pointed out.

It was in early June that he first took up the question of this eye-bar chord. While he was working on this chord, on July 10, Mr. Szlapka brought him a new packing which he refused again to approve, and it was not until July 31 that he succeeded in getting from the Phoenix Bridge Co. a satisfactory chord packing, in conformity with his views and requirements.

Mr. Cooper testified that he would have been glad to have had the physical strength and the time allowed him to have given further study to many parts of this structure, but in his physical condition he was compelled, and accepted the responsibility for the same, to rely to some extent upon others. He said he had implicit confidence in the honesty and ability of Mr. Szlapka, the designing engineer of the Phoenix Bridge Co., and when he (the witness) was unable to give matters the careful study that it was his duty to give them, he accepted the work to some extent upon his faith in Mr. Szlapka's ability and probity.

The inspection was not properly the duty of the consulting engineer, and the organization was not in accordance with his advice. Long before any work of construction was started at the shops the chief engineer of the Quebec Bridge Co. asked him in regard to the matter of the inspection, and Mr. Cooper outlined the following program, stating that the inspection of the shop work on this structure was far greater and more important than anything that they had had experience with before; that the features of the mechanical work were minor ones, compared with the necessity of watching all the technical features of the plans, and that technical engineers, if possible with shop experience, who could not only inspect this work in the mechanical requirements, but see that all the technical requirements of the plan and strain sheets were properly executed, should be employed. Mr. Cooper expressed a desire that technical graduates should be appointed to the position of inspectors at the shops. He pointed out that after the erection work commenced a highly developed class of men would be needed to take charge of that part of the work; it would be very responsible and very difficult to undertake, and he hoped it would be possible to gradually weed out from those who were at the shop men who were competent to take charge of the inspection of the erection after it commenced. Mr. Cooper also pointed out to the chief engineer of the Quebec Bridge Co. that when this bridge was done and finally completed and turned over to the proprietors it would be necessary to have a competent body of engineers to have charge of the structure, its maintenance and general supervision, and that such men should be men who were thoroughly acquainted with the whole history of the construction, the whole theory of the work, and who would be able to know the thing as intimately as possible, in order to maintain and take care of the structure properly. He stated that, in view of this matter, he thought it would be fair and proper that, if it were possible, these inspectors should be Canadians, graduates of Canadian institutions, because the men having charge of this work would have to live there and they should be men of the country.

He did not feel that Mr. Hoare was in sympathy with this matter, and did not succeed in obtaining at that time the men he hoped for. At a conference at Phoenixville about the time the work was under way the necessity of an inspector became imperative, and he stated that he was hampered; that the men's names that Mr. Hoare had sent him did not satisfy him sufficiently to have him recommend them, and that he had no real right to take up that matter. Mr. Reeves, the president of the Phoenix Bridge Co., stated at that time that Mr. Edwards, the inspector at the time of the accident, had been an inspector at their shops for many years, and that they considered him a very competent man; that he was persona grata, and that he would recommend Mr. Cooper to give him consideration. Mr. Cooper had Mr. Edwards come to his office and examined into his history and found that some seventeen years before he had done some inspection for Mr. Cooper that was satisfactory, and that he had been constantly an inspector from that time on, and the witness appointed him inspector at the shops and so reported to Mr. Hoare.

Later on, feeling the necessity of having some one qualified for the inspection of the erection, and failing to get any such person appointed, Mr. Cooper heard of Mr. McLure, bridge inspector at that time on the New York, Ontario & Western Railroad. He sent for him and examined into his career. Mr. Cooper found he was a technical graduate. Witness inquired into his ability to climb and his ability to express himself clearly in regard to technical matters, and concluded that he was a desirable candidate for the position of inspector for the erection. Mr. Cooper again took the initiative and appointed him assistant inspector at the shops, telling him that the ultimate purpose was that, if he proved himself competent after a trial, he should be the inspector of the erection. Mr. Cooper sent him to the shops, under instructions that, while he was to give sufficient attention to the mechanical inspection to make himself thoroughly acquainted with the construction of the work, he should bear in mind that his principal duty was to prepare himself for inspecting the erection; that he should make himself thoroughly acquainted with all the strain sheets, not only of the work as it would finally be constructed, but especially the strains due to the erection; that he should be so prepared that when he went to the bridge he would know under every change daily made in the load what the effect would be upon all the members of the structure theoretically, and that it would be his duty to see that they practically met the expectation of the theory. Witness explained to him in a general way the camber necessity, the changes of position of the different members and the necessity of keeping careful and watchful eye on these actions and to know why these modifications were expected, and, when they did not occur, to find out why. Mr. Cooper then privately requested Mr. Szlapka to give all the aid he could in educating Mr. McLure for the position and confidentially to give witness his opinion of Mr. McLure's capacity after he had been there a sufficient time to determine it. Later on Mr. Szlapka reported that he found Mr. McLure very energetic, very active, very bright and thoroughly capable of undertaking the work in view.

Mr. Cooper reported the appointment of Mr. McLure to Mr. Hoare. The general impression left upon Mr. Cooper's mind after communicating with Mr. Hoare, was that he did not want Mr. McLure. He even stated that he had other men in view. The work of erection had progressed to the extent of placing nearly all the lower chord of the anchor arm upon the false work before Mr. Hoare called for Mr. McLure's assistance. He had previously to that forestalled Mr. Cooper's action after the latter had appointed Mr. McLure by notifying Mr. Cooper that he had appointed Mr. Kinloch inspector for the erection. Without any reflection upon Mr. Kinloch, Mr. Cooper considered he was not qualified to do the duty expected of the inspector of erection. When Mr. Hoare sent for Mr. McLure finally, they were wedging out the lower chord for camber, something that Mr. Cooper was thoroughly satisfied neither Mr. Hoare nor Mr. Kinloch understood. He thought that was the reason for calling for Mr. McLure at this late day.

In many directions the workmanship was perfectly satisfactory, but Mr. Cooper had cause to make frequent complaints of the mechanical department, especially regarding the facing of the compression members and the boring of the pin holes. He frequently and strongly expressed his dissatisfaction with the faults that were made, and also required all such faults to be corrected to put the work into a satisfactory shape. Whether that was done he had no personal knowledge except the reports from the Phoenix Bridge Co. and the inspector. During the erection, on June 2, 1906, Mr. McLure reported that when preparing to erect the center posts he found the bearings of the upper parts of this post were not true and straight and sent sketches which indicated very bad shop workmanship. Mr. Cooper instructed him to stop the erection until this was properly corrected and remedied. He reported later that this work had been corrected in accordance with the witness's instructions.

The magnitude of the structure called for much better workmanship than is usual for ordinary bridges and Mr. Cooper did not think that in all matters proper efforts were made to secure such workmanship, particularly in reference to the facing of the compression members and the boring of the pin holes.

The inspection of the work of erection and the taking charge of that work was not the duty of the consulting engineer. It was the duty of the Chief Engineer and his organization, with the sole right to apply to the consulting engineer for advice upon any special problem.

The local staff at Quebec, employed by the Quebec Bridge Co. and the Phoenix Bridge Co., was not fully competent to handle the work, Mr. Cooper testified.

When discussing the necessity of technical men for the inspectors he took the matter up with the Chief Engineer of the Phoenix Bridge Co. and pointed out to him not only the necessity of the Quebec Bridge Co. having competent men in charge of erection, but also the absolute necessity for the Phoenix Bridge Co. to have an engineer on the work at all times who was fully cognizant of the details of the structure, the action of the different members under the different strains and camber movements, and who would have the technical knowledge to take action if, at any time, the theoretical expectations should not be obtained, to determine why such result was not obtained and be able to direct the necessary corrections.

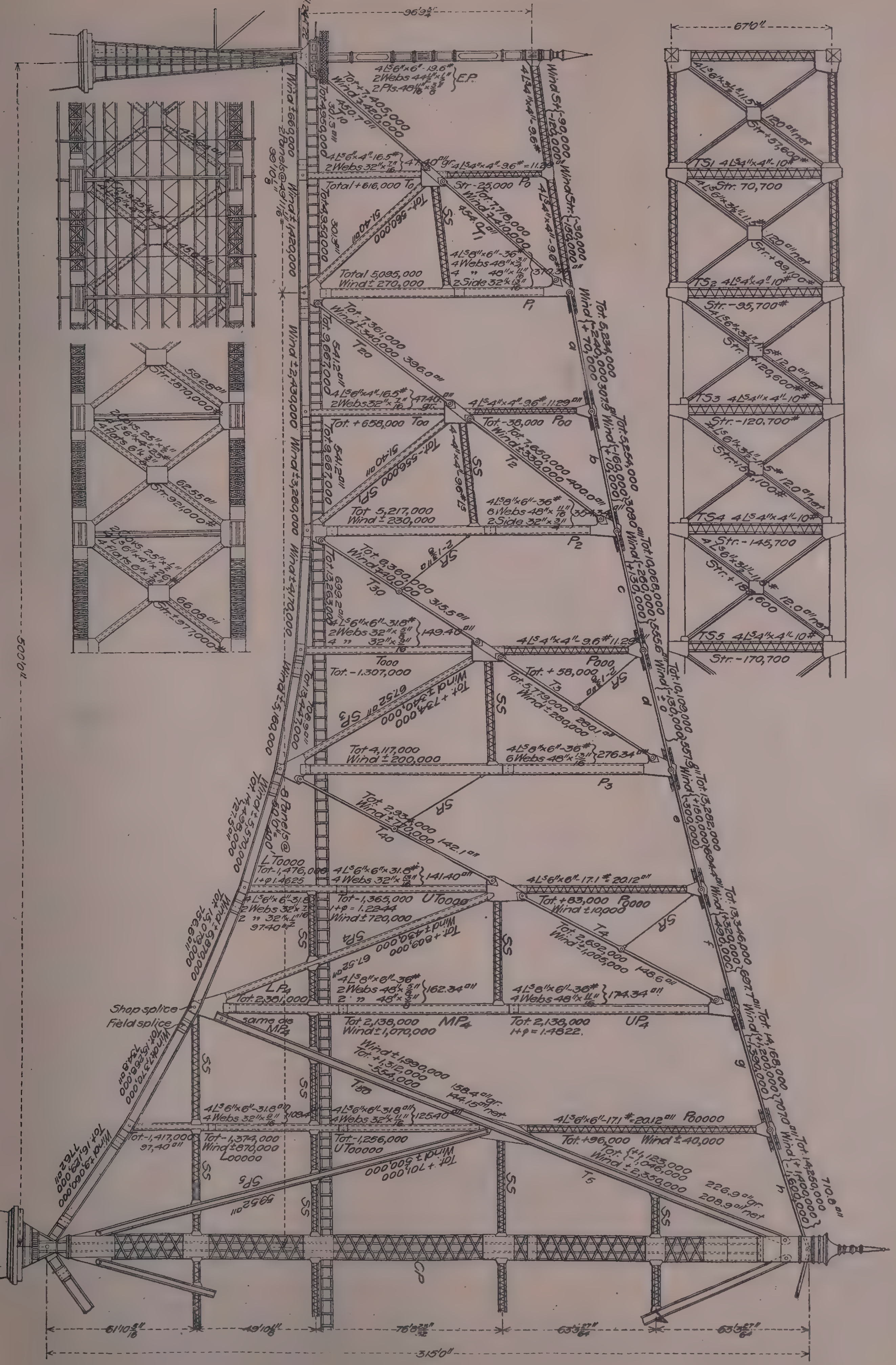
On the part of the Quebec Bridge Co. Mr. McLure was the only person who had any preparation or qualifications for supervising the construction of that bridge, and the time allowed him for preparation for this important duty was not as great as should have been given him. From the reports that he has from time to time sent to witness, from personal intercourse with him, witness believed that Mr. McLure did all that could be expected of him under the circumstances.

For a man to be qualified, in Mr. Cooper's opinion, to have the supreme local control of the erection of a bridge as important as that under consideration, Mr. Cooper thought he should have been a thoroughly technically educated and experienced bridge engineer. Mr. Cooper did not think the Chief Engineer of the Quebec Bridge Co. had these qualifications. In reference to the local control by the Phoenix Bridge Co., Mr. Cooper did not think they had the quality of engineer that the circumstances demanded. In saying this he did not wish to reflect in any manner upon Mr. Birks, who sacrificed his life and who undoubtedly was a competent man in his line of experience; but Mr. Cooper did not understand that he had the thorough training and knowledge of all the requirements of this structure necessary to fit him for the responsible position as the engineering representative of the contractor on such an important structure.

The employment of a staff not equal in caliber to the difficulties of the undertaking on the part both of the Quebec Bridge Co. and of the Phoenix Bridge Co. was difficult for Mr. Cooper to explain. He supposed that in the case of the Quebec Bridge Co., like all projects undertaken by men not specially acquainted with the engineering features of any such great work, they were unable to make a proper selection. In reference to the Phoenix Bridge Co., he thought it was due to the fact that the commercial branch of that company gave more consideration to the pushing and completing of the work than they did to the giving of due consideration to the practical requirements of such a great structure. He testified that it was the general practice in America to have the mechanically trained staff of contracting companies prepare the working plans. As a rule, no consulting engineer could afford to maintain a staff of such character and no corporation would listen to a fee that would cover any such expense.

The methods of erection were submitted to Mr. Cooper unofficially, not for his criticism, nor that they came within his authority, but for personal interest. As previously stated, he stopped the erection of the center post until it was made satisfactory.

In the latter part of September, 1906, on receipt of Mr. McLure's letter of Sept. 22, 1906, and letters following, it was made clear to Mr. Cooper that the anchor arm was not acting in accordance with the theoretical ex-



Principal Maximum Stresses and Materials for the Anchor Arm Trusses of the Quebec Bridge.

Reprinted from The Engineering Record of December 1, 1906.

pectations. On studying the detailed reports of Mr. McLure and the levels contained in his reports, Mr. Cooper found that instead of the anchor arm working itself free from the falsework near chords 8, 9 and 10 first, as it should have done, it was showing a tendency to lift at the far shore end. This was so anomalous that he sought for the reason and came to the conclusion that they had not considered the compression of the main center post under the additional load of the cantilever arm; that this was throwing an undue load upon the bents near point 9 of the anchor arm, and without giving at that time, Sept. 24, any positive orders, Mr. Cooper drew Mr. McLure's attention to this point, believing that he and the engineer of the Phoenix Bridge Co. were also watching for these contingencies and would take the proper action to remedy the difficulty.

It appears that nothing was done by the Phoenix Bridge Co. until several weeks later when, in an interview with Mr. Szlapka at Mr. Cooper's office, the latter showed Mr. Szlapka the correspondence between Mr. McLure and himself and pointed out what he considered to be the difficulty. Mr. Szlapka acknowledged the theory upon which Mr. Cooper was working and sent orders to Phoenixville to take the proper steps to relieve this undue strain at this point. There was some friction between Mr. McLure and the superintendent of erection in reference to this matter, indicating that the Phoenix Bridge Co did not recognize the rights of anybody except themselves to control the erection. That point was brought up in a later discussion with Mr. Szlapka in an amicable way and Mr. Cooper distinctly told him that the Phoenix Bridge Co. were not the only parties who had a financial interest in this structure, that the parties whom the witness represented, the Quebec Bridge Co., had paid for the structure as it stood, that it belonged to them and they had an interest in seeing that it was not risked or injured. If it came to a point of determining his right or the right of any employee under him to protect the property of the company, Mr. Cooper thought they would find themselves in the wrong.

The leaving the position of this chord at that time, with the falseworks not lowered to their proper position, could have produced an undue and an unprovided-for strain near lower chord 9 of the anchor arm, in Mr. Cooper's opinion, especially considering that at that time the splices, which were the weakest and most hazardous portions of the structure, were not riveted and perhaps not fully and properly bolted.

As far as Mr. Cooper knew, all difficulties, all questions, all decisions on any matter relating to the structure were referred to him, and practically he was acting not only as the consulting engineer, but as the chief engineer of the Quebec Bridge.

At the original interview when he made the offer to undertake the examination of the competitive plans he was asked what his fee would be to act as consulting engineer when the work was started. He stated that his fee would be $7,500 a year for such services. He did not recognize at that time that there was to be any expense except an occasional visit to Quebec, so that he made no agreement regarding expenses. In August, 1901, being in Quebec and his fees backward in payment, finding that the company apparently were embarrassed for funds and considering that under the circumstances then before him it might be some years before any actual and important work would be required from him as consulting engineer, he wrote a new offer which amounted to reducing his fee to one-half. A member of the Board suggested at that time to make it the round sum of $4,000 instead of the one-half which was offered. That amount has been paid to him up to the commencement of this year.

When other duties than those of the consulting engineer began to be placed upon him, he suggested to Mr. Hoare that it was hardly fair, considering that he had reduced his fee to one-half, that he should not be granted some additional remuneration to aid him in carrying out the duties that had been placed upon him. No such additional remuneration was ever granted and no offer has ever been made to restore his original fee. His staff and office expenses due to the work required in the interest of the Quebec Bridge Co. were paid entirely from his own fee and they have amounted to approximately the sum that he received from the Quebec Bridge Co. to cover his employment.

With regard to what deviation of a rib of a main compression member from the straight would be passed in first-class inspection and what variation from the true plane is permissible in the faced ends of the ribs at butt joints, Mr. Cooper testified that it is impossible to draw any general and definite rule that applies to all cases. There must be a certain amount of engineering judgment applied to each special case, but in a general way, bearing in mind the compression chords of this structure, that any deviations from a straight line corresponding to the axis of the member exceeding ½ in. would not be good, and if this amount of deviation is only for a short length it becomes far more serious. In regard to the amount of error that might be permitted in facing the ends of compression members, bearing in mind the large dimensions of those in this structure and the importance of having the best workmanship on account of the high demands made on all parts of the structure, 1/64-in. variation from a straight line on the full width of the lower chord would be the extreme limit that should be permitted.

In the early stages of the erection, long before the large traveler was passed over to the cantilever arm, Mr. Cooper drew Mr. Szlapka's attention to the undesirability of using the large traveler for erecting the suspended span, pointing out that it was unduly hazardous and was unnecessary for various reasons. He agreed to have a small traveler designed for the purpose of erecting the suspended span. The small traveler was designed and they then appealed to Mr. Cooper that it would be necessary to use the large traveler for the purpose of erecting the small traveler into position. Mr. Cooper gave consent to that being done, but it was clearly understood that as soon as the small traveler was erected, the big traveler would be removed from this structure and that the erection of the suspended span would be continued with the use of the small traveler only. He was under the supposition that the large traveler was being taken down. He knew they had commenced to take it down, and was very much astonished when he found that they were continuing the erection of the suspended span with the use of the small traveler and most of the weight of the large traveler still at the extreme point of the cantilever arm.

In Mr. Cooper's opinion, the weakest and most hazardous part of the design was unquestionably the splices of the lower chord. While, from the appearance of the wreck, these splices when properly and fully riveted were the strongest part of the compression chord, when unriveted or improperly bolted they were in a condition of great hazard and uncertainty. As these splices in the anchor arm could not be riveted until the camber action had taken place and the joints had come to full and proper bearing, they were, if improperly stayed and bolted, very dangerous points and should have been most carefully watched and protected. From the report of the condition of splice 7-8, cantilever arm, which is contained in correspondence following Aug. 6, 1907, there was first made clear to Mr. Cooper the seriousness of these splices and the lack of appreciation of the necessary care to be given them by the Phoenix Bridge Co.

Mr. Cooper testified that he was satisfied that the initial point of failure was west chord 9 in the anchor arm. His testimony concerning his knowledge of the failure and the events leading up to it was as follows:

"On the morning of Aug. 29, on reaching my office somewhere about 11.25 o'clock, I found Mr. McLure at the office. After speaking to him I passed to my office and took up my morning mail, among which was the communication of Mr. McLure narrating the condition of chord 9, west, anchor arm. After carefully reading and considering the letter I called Mr. McLure into my office and cross-examined him to find out whether the facts given were actual or whether he had been scared, and satisfying myself that the data there were from actual measurement and actual observation, I said: 'It is very serious.' He said: 'Mr. Cooper, they have moved out the small traveler, but we have estimated that it will not add to the strain on chord 9 more than 50 lb. per square inch, but they are going on this morning to erect more of the work; do you think that is right?' I said: 'By no means right.'

"I said: 'Is Mr. Milliken on the work?'—intending to immediately telegraph orders to Mr. Milliken to stop it. 'No,' he said, 'Mr. Milliken is not present on the work; there is only a foreman present.' 'Well,' I said, 'I do not know whether a foreman would take a suggestion from me or not; I will have to telegraph immediately to the Phoenix Bridge Co. for them to wire to the bridge,'

"I said: 'Are you sure that the Phoenix Bridge Co. have these same facts before them that you have presented to me?' And he said: 'Exactly the same report has gone to Phoenixville that you have now received.' That was confirmed by a telegram handed me about the same time from Mr. Hoare, stating that Mr. Birks had received a telegram from Phoenixville stating that this chord had been bent before it left the shop. Satisfied then that the Phoenix Bridge Co. had the same facts I immediately telegraphed them to 'add no more load to bridge till after due consideration of facts.'

"I then said to Mr. McLure: 'You must go to Phoenixville immediately and tell the Phoenix Bridge Co. that I do not want any delay such as that involved in the discussion that we have had heretofore on similar occasions, but I want immediate action to strengthen that chord and to protect the bridge.' He pulled out his time table and said: 'Mr. Cooper, I cannot reach Phoenixville before five o'clock.' I then added to the despatch: 'Mr. McLure will be over at 5 o'clock.' Mr. Berger went to the Western Union office and they had the telegram endorsed : 'Sent from the Western Union office at 12.16 p. m.'

"I immediately took up the problem of how to protect and how to strengthen that chord and made some sketches which I showed to Mr. Berger. I said: 'If the Phoenix Bridge Co. do not themselves adopt some better method I would suggest that to them.' At 9 o'clock that evening I was called up on the long-distance telephone and Mr. McLure reported that the bridge was in the river.

"I think the deflection of an important member, as chord 9 west, to the extent of 2¼ in. would indicate to any intelligent mind that that chord was less capable of doing the duty that it would have done if in a perfectly straight condition and I do think that it was perfectly possible by prompt and intelligent action to have stayed that chord and prevented the failure of the bridge."

Testimony of Peter L. Szlapka.

Mr. Szlapka, designing engineer of the Phoenix Bridge Co., testified that the general design of the Quebec bridge was prepared in the company's designing department under his personal direction. The work was then turned over to Mr. Scheidl, engineer in charge of the shop drawings. The main features of the design were explained and complete specifications, as prepared by the Consulting Engineer, were given to him for his guidance in designing the details of the bridge. After preparing the general preliminary details of the most important connections, Mr. Scheidl discussed them with Mr. Szlapka and changes were made if found necessary. These preliminary drawings were discussed with Mr. Cooper and changes made as directed by him. After these preliminary details were established to the Phoenix company's complete satisfaction an assistant engineer and a number of first-class draftsmen (varying from five to fifteen) were assigned to Mr. Scheidl's charge, who prepared the final shop drawings, using the preliminary plans for their guide. The final shop drawings were only then considered as complete, after being changed as many as seven or eight times. The general calculations were checked twice in the designing department and twice in the drawing room during the preparation of shop drawings.

Speaking in a general way, Mr. Szlapka said he designed the bridge; it is, however, of such a magnitude as to be beyond the ability and physical endurance of one man. The results achieved represent combined efforts on the part of all the departments of the Phoenix Bridge Co., under the direction of the consulting engineer, Theodore Cooper.

The regular organization of his department and of the drawing room Mr. Szlapka considered entirely capable of dealing with the problem. No addition was found necessary. The shop drawings were first checked by Mr. Scheidl, the engineer in charge, as to strength, general clearances, facility of erection and connections with other members. The assistant engineer, under immediate charge of Mr. Scheidl, checked the drawings as to their correctness for all connections and for shop work. At certain stages of the work, when the drawings were too far ahead of the checking, as many as six engineers and five of the best draftsmen were used as additional help in checking. The few errors found during erection the witness considered the best evidence of how carefully all the shop drawings were prepared and checked.

The information in the Phoenix plan 1, dated Nov. 30, 1897, referring to the length of spans, cross-section of river and the clear height of bridge, was furnished by Mr. Hoare, chief engineer of the Quebec Bridge Co. The company's plan No. 2, dated Dec. 7, 1897, is identical as regards the superstructure, with a plan dated Jan. 13, 1898, signed by Messrs. Parent, Barthe and Hoare, of the Quebec Bridge Co. A plan dated Jan. 13, 1898, is practically a copy of the plan of Dec. 7, 1897.

In designing the 1600-ft. span first talked about, the Quebec Bridge Co.'s specifications were followed in every particular, except as regards wind pressure under 30 deg. to the horizontal, which requirement was disregarded as unnecessarily severe.

The plans submitted with the tender, being only of an approximate character, no recalculations were made based on the approximate weight ascertained from the first calculations. Mr. Szlapka had no doubt at this time as to the existence of data sufficient to enable engineers to design the bridge, especially in regard to large compression members.

About April, 1900, Mr. Szlapka received orders from Mr. Deans to prepare a plan with a central span of 1,800 ft. Not understanding that the length must be exactly 1,800 ft., the panel lengths working out better for a slightly shorter span, Mr. Szlapka selected a central span of 1,723 ft., keeping the length between the anchorages 2,800 ft., as required. After he was informed that the central span must be exactly 1,800 ft., he prepared another plan in harmony with these instructions. Subsequent to April 22, 1900, he made several general plans of the Quebec bridge, all of which show the river span at 1,800 ft. The change in span from 1,600 to 1,800 ft. was considered by the witness to be entirely feasible from an engineering point of view.

During May and June, 1900, after the 1,800-ft. span had been adopted, only the suspended span and the cantilever-arms were recalculated for the new length of the central span, according to the Quebec Bridge Co.'s specifications. No table of weights was prepared at this time. As regards the lengths of the cantilever-arms and the suspended span, the latter was made three-eighths of the main central span; the usual length of the suspended span varies from three-eighths to one-half of the central span. Witness selected the lower limit in order to reduce the erection stresses at the connection of the suspended span with the cantilever-arm. He also believed that this arrangement enhanced the beauty of the design.

The anchor-arm was made 500 ft. by order of the chief engineer of the Quebec Bridge Co., which length appeared to be desirable in order to avoid reversed stresses in the top and bottom chords, according to the different positions of the live load.

A continuous study was given to the general design, while the details were perfected as the work progressed. The final design, Mr. Szlapka believed, could not be improved upon. Many of the details were roughly sketched out as early as 1897 and 1898. All important general details were drawn out by Mr. Scheidl during 1902 as a basis for further study and perfection. The details at that time not being final, their weights were not ascertained in order to compare them with the rough weights of details assumed in the calculations.

The outline of the bridge was discussed with Mr. Cooper fully. The lengths of the cantilever-arm and the suspended span were approved by him, while the length of the anchor-arm was specified by the chief engineer of the Quebec Bridge Co., governed by local conditions. The panel length, the arrangement of the web system and the depths of the trusses were discussed and approved. Mr. Cooper was at first of the opinion that trusses inclined from the vertical would be preferable, so that the effect of any settlement of the main piers would not be as readily perceived as in the case of vertical trusses, when one or both trusses might be out of vertical. This question was finally settled by Mr. Cooper in favor of vertical trusses in October, 1903. Another point raised by Mr. Cooper was the vertical end posts of the anchor-arm. His attention was called to the fact that the vertical posts were preferable to inclined end posts admitting of simpler details for end portals, and, at the same time, giving to the anchor-arms the appearance of greater length than would be the case with the inclined end posts. This question was also settled by Mr. Cooper in favor of vertical end posts in October, 1903.

The floor system was figured first beginning July 1, 1903, followed by calculations of the suspended span during the period from November, 1903, to February, 1904. The weights of the cantilever-arm and suspended span were then believed to be sufficiently accurate, and were so approved by Mr. Cooper, to enable the witness to correctly design the anchor-arm. Subsequently, when the suspended span and cantilever-arm were developed, it was found that the actual weights were somewhat in excess of those assumed for the calculation of the anchor-arm.

On May 13, 1903, the Phoenix Bridge Co. received a letter from Mr. Cooper stating that he was ready to see Mr. Szlapka to talk over specifications for the main bridge. Mr. Szlapka visited Mr. Cooper on May 14 and received from him a full explanation of the loading and unit stresses to be used in proportioning the members of the main bridge. Mr. Cooper impressed upon the witness the importance of strictly following his specifications, but at the same time to be prepared to consider special important features with him irrespective of the requirements of his written specifications. In view of Mr. Cooper's proposition to use, for certain combinations of conditions, unit stresses as high as 24,000 lb., or three-quarters of an average elastic limit of 32,000 lb., Mr. Szlapka mentioned to Mr. Cooper the fact that a German professor proposed to use a fraction of the elastic limit for unit stresses for truss members after first allowing for irregularity of shop work, for imperfect erection, for flaws in material, etc. A table showing extreme velocities of wind at various stations, as reported by the United States Government, from 1883 to 1893, was presented by Mr. Szlapka to Mr. Cooper for his consideration in discussing the question of wind pressures. Mr. Szlapka did not suggest any modifications in the Quebec Bridge Co.'s specifications. After learning from Mr. Cooper his exact wishes as to the loading and unit stresses, the calculations were begun on the floor system, followed by the 675-ft. suspended span. The amendments made in the specifications by Mr. Cooper were not subject to Mr. Szlapka's approval.

The unit stresses used in the designing of the anchor arm, as determined under the revised specifications adopted by Mr. Cooper, were considered by Mr. Szlapka up to the extreme limit of economy in design and safety to the structure. In finally developing the stress sheet for the cantilever arm and the suspended span, it was found that the weights produced were in excess of those estimated in the design of the anchor arm, and these excess weights tended to increase the stresses in the anchor arm. The detail design of anchor arm was not altered so as to meet these increased stresses, however. The weights of the suspended span and of the cantilever arm, assumed in the first calculation of the stresses of the anchor arm, were smaller than the weights as finally obtained. Consequently, the stresses of the anchor arm, due to these increased weights, were increased, the anchor arm having been built in the meantime. Mr. Szlapka considered that these increases in unit stresses were still within the limits of safety.

The whole scheme of the bridge could not be fully considered in detail before shop work commenced. General experience enabled the Phoenix Bridge Co. to proceed without occupying valuable time and the time limit precluded any such arrangement. The ordinary rule, which is imperative in all cases, irrespective of the unprecedented dimensions of this strucrue, was followed.

Mr. Szlapka testified that his relations with Mr. Cooper were of a perfectly cordial nature throughout the whole period of the designing and erecting of the Quebec bridge. Mr. Cooper's criticism of plans and design was such as might be expected from an engineer of his experience and ability. Mr. Cooper was aware of the exact conditions of design on Oct. 1, 1904, at which period he approved the design of a large portion of the anchor arm, and was aware that strain sheets for the cantilever arm had not been made. He ordered no recalculations made. Knowing, however, that the weights assumed for calculations were exceeded by the actual shipping weights as reported to him by his inspectors, he, no doubt, made some calculations, as he remarked to Mr. Szlapka on one occasion during 1906 that "this fact did not amount to anything."

Mr. Cooper, among others, made the following suggestions:

First. Arrange anchorage of wind bent on anchor piers so that anchor bolts resist wind shear only, while the upward pull is transmitted to the anchor pier by the anchor bars only. Adopted.

Second. Change friction (due to lateral wind pressure and change of temperature) between end floorbeam of anchor arm and top strut of wind bent from sliding to rolling friction. Adopted.

Third. Arrange expansion of floor system so that no undue bending is produced in the floorbeams. Adopted

Fourth. Arrange expansion between suspended span and cantilever arm, at both ends, instead of at one end as proposed by the Phoenix Bridge Co. Adopted, but not considered an improvement by Mr. Szlapka.

Fifth. Arrange packing of eyebars in top chord of anchor arms, as per Mr. Cooper's two sketches. Not adopted. Found entirely faulty by the Engineering Department. The Phoenix Bridge Co.'s packing adopted with very small modifications suggested by Mr. Cooper.

Sixth. Provide wooden traction arrangement between suspended span and cantilever arms, as shown on Mr. Cooper's sketch. Not adopted, as not being in harmony with the high standard of the rest of the details of the bridge. Its design was still open when the bridge fell. Mr. Cooper urged the adoption of this wooden arrangement as it could easily be made by a track-walker and attended to by him in case of repairs. Not wishing to criticise Mr. Cooper's scheme, Mr. Szlapka remarked that it might be criticized by the profession; to this Mr. Cooper answered "there is nobody competent to criticize us."

Seventh. Change lateral bracing in floor system, as per Mr. Cooper's letter. Not adopted, as inferior to the Phoenix Bridge Co.'s design.

From his personal observations, Mr. Szlapka believed that all plans were carefully examined in Mr. Cooper's office; either by Mr. Cooper personally, or by his assistant; the latter reporting on all important questions to Mr. Cooper. The fact that even unimportant mismatched connections did not escape the attention of Mr. Cooper's office certainly proves the thoroughness and careful study bestowed on the examination of the plans. Considering Mr. Cooper one of the ablest and most experienced bridge engineers in the country, Mr. Szlapka discussed fully with him all main features of the bridge. His advice and directions were always sought and appreciated.

After the first sections of the lower chords of the anchor arms were constructed in the shops, Mr. Reeves, President of the Phoenix Bridge Co., remarked, in the company's engineering office, that the lattices on the chords appeared too light and that they were liable to be injured or damaged in handling in the shops and transportation to site. Mr. Szlapka answered that lattices of any size might be injured and destroyed if carelessly handled in the shop or in transportation. This conversation was reported by Mr. Szlapka to Mr. Cooper. He answered that he looked into the question of the strength of the lattices while checking the plans and that "we had it all right."

Mr. Cooper was aware that it was the intention to use the large traveler for erection purposes as far as the center of the suspended span, from conversations with Mr. Szlapka, and owing to the fact that he approved the unit-stresses due to the erection based on the above condition.

The first intimation Mr. Szalpka had that led him to suppose that any member in the bridge was showing distress was when his attention was called to the curved condition of chord 9L, south anchor arm, by Mr. Birks' report, enclosing a sketch of the chord, on Aug. 29.

Assuming the bridge to have been successfully completed, the unit-stress in chord 9, anchor arm, was figured by Mr. Szlapka to be 21,200 lb. including live and dead load and snow. In his judgment the weakest parts of the structure, first, during erection, and second, when completely erected, were the compression members of the bridge.

Mr. Szlapka's testimony regarding the failure reads as follows: "It appears reasonable to suppose that after the fall the center of gravity of the top mass of the metal should be on that side of the center line of the bridge on which the initial failure of any important truss member took place. This condition of the top chords actually existing clearly indicates to my mind that east chord section 9, south anchor arm, failed first, dragging the west chord, section 9, after it. The two main shoes have been pushed off their pedestals towards the south anchor pier by an unbalanced horizontal force over the main pier. This condition was created by the destruction of chord 9, anchor arm, and the release of the horizontal component of chord 10, cantilever arm."

The reason he assigned for chord 9 in the anchor arm yielding under a unit-stress of 18,000 lb., when they were calculated to safely carry a much higher unit-stress, is that the main sections, being sufficient to resist the stresses existing on that day, either the detail parts uniting the four ribs failed, or the ribs buckled individually, or both.

In Mr. Szlapka's opinion there is no reliable theory established, nor are there any results of extensive tests on compression members on record as regards detailing of these large members. No data exists showing clearly when lattices only are sufficient to unite fully two or more ribs into one rigid unit. There is, no doubt, a limit to the depths of compression members when lattices only may be used, and when, on the center line of the ribs, in addition to the lattices, a continuous horizontal plate-girder must be added. We have no data, in his opinion, showing how much more efficient top and bottom cover plates are than heavy lattices, nor do we know when, in addition to top and bottom cover plates on the center line of the ribs, girders as above mentioned should be used. All doubt as regards these important features of detailing large compression members should be eliminated by extensive tests, as arguments advanced by theoretical investigations are based on more or less vague assumptions. It is the duty of the entire engineering profession to strive to secure numerous tests to establish rules to be followed in designing compression members of large size, in order to replace or to corroborate present opinions.

In splicing large compression members Mr. Szlapka considers that the area of the splice-plates would be sufficient if they represented from 15 to 20 per cent. of the area of the members. A splice which was to be 60 per cent. bolted up he considers properly bolted if 30 per cent. drift-pins were used. The anchor arm, during erection, acted generally as expected. Considering the height of the falsework, 160 ft., the wooden falsework foundations resting on natural ground, the variations in the field as compared with the office calculations were insignificant.

Secondary stresses due to the enforced position of the members in the structure were considered; but no allowance was made for them.

First—In floorbeams due to bending induced by railroad stringers during change of panel lengths of trusses. No allowance made, as directed by Mr. Cooper.

Second—In eyebars due to bending induced by deviation of the bars from longitudinal axis of bridge. No allowance made as directed by Mr. Cooper.

Third—In end vertical posts of suspended span due to temperature change. Insignificant.

Combinations of wind and loading, assuming the load increased by 50 per cent., would produce unit-stresses in the cantilever-arm as follows: Chord 7, 25,600 lb.; chord 8, 25,900 lb.; chord 9, 26,800 lb.; chord 10, 26,400 lb. These unit-stresses were approved by Mr. Cooper.

The combination of conditions of loading being practically impossible, Mr. Szlapka did not believe that the efficiency of the bridge was affected by the high unit-stresses given above.

In order to begin the erection of the north anchor-arm early in the spring of 1908, the large traveler had to be removed from the south side and re-erected on the north side in the fall of 1907 before it was possible to finish the erection of the entire south half of the central span. Therefore, another traveler had to be provided for the erection of the south half of the suspended span, only about one-quarter as large as the large traveler, thus effecting a considerable saving of metal in the suspended span.

The use of this small traveler was first suggested, and finally decided upon, by the Phoenix Bridge Co. about January of 1906, with Mr. Szlapka's full approval. The original scheme of erection contemplated the use of the large traveler to the center of the suspended span; the erection stresses in the cantilever-arms were so figured and sizes provided. The stress sheet of the cantilever-arm was approved by Mr. Cooper, showing sizes for erection stresses for the above condition. Stresses in the suspended span, due to small traveler, were only about 25 per cent. to 33 per cent. of the stresses due to the large traveler.

Knowing that every part of the bridge was figured with the utmost care as to its strength, that the results of the calculations were checked and compared at least three times in the Phoenix Bridge Co.'s office, that they were then sent to the consulting engineer for comparison with his calculations and for his approval, and that they were fully approved by him; knowing further that the shop plans were prepared under the witness's personal supervision by a corps of able engineers and draftsmen, that these plans were redrawn several times; that they were then sent to the consulting engineer for his study and approval and that they were all approved by him; knowing further that every part of the bridge was constructed strictly in accordance with these plans; knowing also that the erection was conducted carefully and strictly according to plans prepared by the engineering department—knowing all these facts, Mr. Szlapka was forced to believe on Aug. 29, 1907, that the bridge was in a safe condition, and that no part could show the least sign of weakness due to stress, especially as the loads of the bridge on that day were such as to produce stresses in the truss members only about three-fourths of the stresses the bridge was figured to be able to bear with entire safety after its final completion.

It was impossible for him to believe that the bridge was failing or that the amount of curvature in chord 9L was as reported. The resident engineer, Mr. Birks, stating on Aug. 29, on the telephone, that there was no distortion in any lattice, that all rivets were tight, that there was no change taking place in any part of the chord, Mr. Szlapka was further strengthened in his belief that there was nothing wrong with that member. He made rough calculations of the chord, however, using 14,000,000 lb. axial stress, and an average curvature for the four ribs of the chord of 1½ in., and found that even with this improbable curvature, the chord was not in a dangerous condition.

Testimony of Charles Scheidl.

Mr. Scheidl was assistant engineer in charge of the drafting work of the Phoenix Bridge Co. for about eight years, and as such looked after the details of the design of the Quebec bridge. The first step taken was to determine how the suspended span would be connected to the cantilever arms, then the shoes for the main posts were considered, and after that the anchorages were considered.

The details for the suspended span were those generally used. The details at intersections of top of hangers and top of sub-posts were first tried with one pin, but the connections made the one pin very long and the connected members had undesirable, long, weak jaws, while with the introduction of links the hanger and sub-verticals could be connected in a most satisfactory and substantial manner to the transverse bracing, giving greater stiffness. Besides, the difficulties of erection were reduced, as otherwise the traveler would have had a much greater overhang and this would not only have increased the weight of the traveler, but also the weight of the structure.

The next study was the arrangement of the top chord packing for cantilever and anchor arms. Links fast to posts for diagonal eyebars were deemed necessary. For the top chord connections at the main post of the cantilever it was proposed to use only one pin at these apices. The details of the principal panel connections were drawn out next. The links for the connection at the bottom end of the diagonal eyebars were first designed fast to the bottom chord as being more desirable and smaller in size, but this scheme had to be given up as the connections of the floorbeams to the post and the bottom chords became weaker, while links fast to the posts gave a splendid connection between the floorbeams and posts.

The main shoes and main posts were next gone into. Extraordinary dimensions were required for the pedestals under the main shoes to distribute properly such an enormous weight over the masonry. The original idea was to build each tier of pedestals in one piece, but shipping limits forbade this and special milling machines had to be constructed. The shoe had been so designed that all loads passed through its pin, but the scheme of letting the main post bear directly on the pedestals while shear from the bottom chords only passed through the shoe pin was considered too. Special attention had been given to transferring all wind loads collecting near the shoe into the masonry. The detail at the top of the main post was at first tried with one pin, but two pins were found necessary. The main post had been so designed that the placing of its ribs gave the best resistance to bending of that part of the post where transverse bracing had to be omitted for the passage of trains and wagons, while the ribs of the posts near the top and bottom had to be placed in a longitudinal direction.

The preliminary detailing began in July, 1903, after the receipt of the revised specifications. The first step was to determine the normal lengths of all bridge members. As the trusses had not a single horizontal member, all inclined members were designated by ordinates and co-ordinates and the elevation of any panel point could quickly be checked without knowing the length of any inclined member. Next, preliminary drawings of all plate and trussed floorbeams and of all stringers were made and sent for approval. Then details showing the type of transverse bracing were made for approval, and details showing the main shoes, pedestals, connecting chords, and their bracing.

The arrangement of the eyebars for the anchor arm required considerable study, as the bending moments on the pins was not allowed to exceed the allowed values of a 12-in. round pin. The final decision was to have no eyebars thinner than 1¼ in., nor thicker than 2 1/16 in. To avoid additional stresses on eyebars, the skew in regard to the center line of the trusses was not allowed to exceed 4 in. in 50 ft. If the skew could not be kept within that limit on account of clearances for bridge, the eyebars were bored skew to eliminate additional stresses in the eyebars and the method of marking such eyebars was most distinct and precise, so as to make sure that any such bars would not be placed the wrong way in the bridge. The sides of these eyebars were marked before being removed from the boring machine and the heads were painted "Inside" and "Outside" with different colors.

In all cases the desire was to avoid difficult calculations by placing the eyebars so that moments could be reduced to zero as often as possible. All eyebars were so grouped and the ribs of the chords were so divided that all ribs at connections were packed alike, and, therefore, stressed alike. In all top chords the stresses coming from the diagonals were counterbalanced by eyebars in the chords placed so that this transfer was practically direct, while the rest of the chord eyebars, getting their stresses from former panel points, were side-lined.

The details for anchorages were worked out next. The method of transferring wind shear at the end of the anchor arm to the masonry had been made through checks between the end floorbeams and the top strut of the wind bent. The uplift caused from wind had been taken care of by means of long foundation bolts. This wind uplift was finally ordered to be taken care of by the main anchor bars themselves, and only the horizontal transverse shear was resisted by foundation bolts. The transferring of wind stress from the end of the anchor arm to the top strut of the wind bent was finally accomplished by means of a tenon girder which had a roller bearing against the top strut of the wind bent, and could move in any direction, whether the movement was caused by temperature or by change in the loading of the bridge.

The lengths of all stringers were determined by calculating the length of the chords for all the different ways of loading and finding the lengths of stringers according to their elevation between chords. These stringer lengths were fixed so as to give the least bending in the floorbeams. The result was that every other panel had an expansion joint. At expansion joints the railway stringers only were fast to the floorbeams on one side, while all other stringers were slightly loose, so that the bending of the floorbeams could not take place in the short distance between the chords and the nearest stringer.

The preliminary detail of all anchor-arm panel points was started at this time, commencing with the end bottom chord. All ribs of chords were so arranged as to divide each truss connection into two, three, four or five equal ribs. Though all main posts consisted of only two ribs, the ends had to be provided with four or more ribs for proper chord connection.

Sub-posts and hangers were built of only two ribs throughout, but where they were connected to a four-rib detail each rib received a quarter of the stress in vertical and horizontal directions. Wherever additional ribs and posts were placed, all such connections fully provided for shear, chord stresses, etc. The bearing values on pins had been made 1½ times the allowed stress, but this was later changed to 1¼ times the allowed stress. Shear on pins was made ¾ times the allowed stress. The net section through the pinhole was made first 1¼ times and later 1.3 times the net section of the member, while the net section back of the pinholes was made ¾ of that through the pinhole. In determining the net sections through pinholes not only were the rivets directly opposite the pin considered, but the placing of any rivets in such links was most carefully followed throughout. The net sections of all riveted tension members were found by assuming the rupture to take place through any diagonal line of rivet holes where the net section does not exceed by 30 per cent the net section of the transverse line.

All panel points of the anchor-arm had been sketched out in the most studious way. Most points were shown giving several ways of making the connections until a final one had been selected. As these sheets showed not only every detail but all the calculation throughout, it was an easy matter for any draftsman to make final shop drawings from them in a most intelligent manner.

When the details for the anchor-arm were completed and those for the cantilever-arm partially completed, the weights of all details were calculated by the computing department and the final anchor-arm stress sheets furnished.

Before commencing the shop work on the anchor-arm a clear understanding with the erection department had to be arrived at as to where the field splices had to be finally placed. As an overhead traveler, running on falsework and straddling both anchor-arm trusses was provided for, the erection problem of the anchor-arm was simplified as far as the office work was concerned.

Before any shop drawing of the larger pieces could be made, sketches giving the extreme dimensions, weight, etc., had to be made for the different railroad companies. This took considerable time, as these companies had not only to determine if these large pieces could be shipped over their own lines, but if they could be shipped the whole distance from shop to bridge site. Such sketches were, in many cases, quite extensive drawings requiring much time in the office for preparation and often showing special beams, struts, castings, pins, etc., to rig up cars, without reference at all to the work in this line usually done by the shipping department.

The normal condition of the truss shape had been fixed for the position of the live load giving practically the maximum uplift and all cambers were derived from it. All angles and abutting splices were figured for this position so as to be sure that under full loading any extra initial stress would equal zero.

Pinholes for 10½, 12 and 14-in. pins were bored 3/64 in. larger than size of pin. Pinholes for 24-in. pins were bored 1/16 in. larger than size of pin. Pinholes for 7 11/16-in. pins were bored 1/32 in. larger than size of pin. Pinholes for 2 5/16-in. pins were bored 1/50 in. larger than size of pin.

In determining the length of eyebars the first correction was for camber, the second for permanent set, the third correction was on account of play in pinholes, and in eyebars placed skew the fourth correction was for skew. The permanent set in the eyebars was determined by a series of tests. The correction for permanent set in anchor eyebars was 3/64 in. per head, while for the rest of the bridge 1/32 in. only was used, as the eyebars were finally made of a higher ultimate steel. The correction in built lengths was 1/32 in. for each eye.

All rivets were determined by these values: For shop rivets, 1.5 times allowed stress for bearing value; 0.75 time allowed stress for shear. For field rivets, 1.1 times the allowed stress for bearing value; 0.55 time the allowed stress for shear.

In getting out the shop drawings only a small force of expert draftsmen was selected at first and the number was gradually increased. It required three years to complete the office work. It was thought best not to subdivide the work among different assistant engineers, but to give one man full charge from beginning to end. All drawings were prepared under his direction, and whenever a drawing was completed it was examined by him carefully in regard to lengths, sizes, strength of all details, notes for shops, inspectors and transportation. It was only then that these drawings were forwarded in duplicate to the consulting engineer for his approval. If approved, seven additional prints of complete, checked drawings were sent to the consulting engineer for his approval and six copies were returned by him to the bridge company, who sent five copies to the chief engineer of the Quebec Bridge Co. The Phoenix Bridge Co. received one print back approved by the Dominion Government. The drawings were made in such a manner that all information necessary for the proper execution of the work in the shop was given, as clearances, notes explaining any peculiar detail or calling attention to all important dimensions regarding width, depth, etc., and information for the sole use of inspectors.

At no time during the progress of the office work were more than 18 men working upon it at a time. If twice that number had been employed the result would have been the same. The rate of progress depended upon the rapidity with which the person in charge performed his work.

Testimony of David Reeves.

Mr. Reeves testified that he was the president of the Phœnix Bridge Co., which is an engineering and contracting concern, and of the Phœnix Iron Works, which manufactures the structural work for the former company. When the work began he believed the appointment by the Quebec Bridge Co. of Theodore Cooper as consulting engineer assured the success of the undertaking. Mr. Cooper insisted upon having the final authority over his colleagues, and Mr. Reeves regarded his approval of the detailed drawings as of the highest importance. Mr. Cooper was in the shops but twice, only once saw any of the finished bridge members and was never at the bridge site at all after erection started. But his inspectors and the Phœnix inspectors, working independently as checks upon each other, did not use their usual discretion, but reported every error, however slight, directly to Mr. Cooper for his information and approval. This probably caused Mr. Cooper to magnify their importance and to believe an unusual number of errors had been made, which is not true.

The erection of this bridge was an important undertaking, and every precaution was taken to avoid unnecessary risks and our whole organization was impressed with this idea. When the compression chord members began to yield at several places one after another and the whole bridge was on the verge of collapse, as afterwards developed, the Phœnix staff at the bridge site observed the signs, and acted promptly and efficiently. They calculated correctly the stresses on the several members, and decided that failure from such stresses was impossible. When reported to Mr. Cooper he foresaw no immediate danger, and the same was true at the office of the engineers at Phœnixville.

In respect to the sections of the compression members as built for the Quebec bridge, Mr. Reeves said that it was not to the interest of the Phœnix Bridge Co. to restrict their area or weight, but that in a commercial way it was largely to its interest to increase the sections, and the size and weight of the bracing. The contract being not for a lump sum but by the pound, any increase of metal would have been to his company's advantage. It was imperative from the point of view of good engineering not to make the weight or price of the bridge any more than was demanded by the best practice. The consulting engineer in the interest of his clients was supreme in this respect.

Mr. Cooper made modifications in the unit stresses for various members which much increased them beyond any precedent, and by so doing placed the whole design in a field outside the benefit of experience. Such high stresses had never before been used, and in using them he acted with the authority of the Quebec Bridge Co. and the Dominion of Canada vested in him. The fall of the bridge is to be laid directly to the change in the unit stresses made by Mr. Cooper. Some increase of weight, especially in certain compression members, was requisite, and the Phœnix Bridge Co. called this to the attention of the consulting engineer. Mr. Cooper refused to allow any increase in these members.

Testimony of Frank P. Norris.

Mr. Norris testified he was manager of the Phœnix Iron Co., in charge of the production of the material for the Quebec bridge. When the formal contract for the bridge was signed on June 19, 1903, the necessary extensions to the plant and equipment, costing from $225,000 to $250,000, were immediately started. The first working drawings were received at the shops on June 1, 1904, but orders for the steel had been received several days before. Work began on the fabrication on June 24, 1904. All the shapes for the bridge were rolled in the Phœnix works; the plates were furnished by the Central Iron & Steel Co. and the pin material by the Bethlehem Steel Co.

After the members were riveted, they were laid out by the shop superintendent or his assistant before facing them in rotary planers or putting them in the boring mills, and were checked after each cut. In many cases the work was checked by the inspectors of the Quebec Bridge Co. and always by those of the Phœnix Bridge Co. Mr. Norris made a strong plea that the best shop inspectors obtainable should be placed on the work. The consulting engineer stated distinctly that he would not have the inspection done by an inspecting firm, as he wanted men of his own selection who should have no duties but to be right on this work all the time. This met with Mr. Norris's ideas exactly, except that the consulting engineer stated that he wanted young men just out of college who, being without any practical experience, would be trained according to his own ideas. The officials of the company protested against this strongly, and finally Mr. Edwards, a man with some 20 years' experience, was appointed chief shop inspector, and later Mr. Meeser, another experienced inspector, was appointed to assist him. Mr. McLure also spent considerable time assisting Mr. Edwards with the shop inspection before taking up his duties as inspector of erection. Mr. McLure also spent the winter months assisting with shop inspection.

Testimony of E. L. Edwards.

Mr. Edwards testified that he was chief inspector of the Quebec Bridge & Railway Co. at the shops. On the advice of the consulting engineer he conferred with Mr. Szlapka regarding minor errors before the shop was allowed to remedy them. Every error he considered important was referred to Mr. Cooper and his instructions were carried out implicitly. Members for the south side were always remedied promptly.

With respect to the shop work, it was his opinion that the limits to which it was practicable to straighten the ribs of the bottom chord members depended on their thickness and the nature of the bend. If the bend was a long curve it was a comparatively easy matter to take out a 3 to 4-in. bend, but if the bend was a short kink this would be a different proposition and could only be decided by the case at issue. There were no chords on the Quebec bridge where it was necessary to remove any short or sharp kinks. Long bends were always removed before milling.

In matching consecutive chord members the web plates might vary in thickness and angles were not always true, but it was tried to have the ribs absolutely the correct distance apart from top to bottom at ends of chords. He occasionally allowed as much as 1/16 in.; he did not believe it possible to secure greater accuracy than this where measurements were taken between rolled surfaces.

From actual measurements it was learned that the accuracy of the milling done by the rotary planer for the larger members of the Quebec bridge varied from a true plane, where such variation occurred, from 1/64 to 1/32 in. A main post section was found to be out of true 3/64 in. at one corner, but the fact of the bearing surface being great and the unevenness in question being small at one point only, Mr. Edwards deemed it advisable to accept the member, believing that when the weight of the other post sections was on there would be perfect contact.

In the tests for accuracy, the facing was first tested with steel straightedge. Dimensions from the faced end to the center of the pin holes were taken by means of a standardized tape secured at one end of the member by a stop and supported at points the entire length of the piece. To determine the exact center of the pin hole, a circular leaden disk was held in place by three set screws and the exact center was established from four points on the bored surface of pin hole. A spring balance was attached to the tape and 12-lb. tension used in all cases. In measuring distances less than 15 ft. between centers of pin holes, the centers above described were put in, but trammel points were used to check distances in place of the tape. Cast iron gauges about 6 ft. long were put in all pin holes. Care was taken to see not only that the pin would enter the hole without difficulty when the member was erected in the field, but that the allowed clearance between the pin and hole was not exceeded.

While all holes for splice-plate connections were drilled from iron template, the dimensions between the holes were always all carefully measured, and in fact this was done in the case of all open holes.

APPENDIX 5.—THE EFFECT OF FINANCIAL LIMITATIONS UPON THE DESIGN OF THE BRIDGE AND A DISCUSSION OF THE EVIDENCE RELATING TO SAME.

The fact that the carrying out of the bridge project was for years delayed by lack of funds, being a matter of common knowledge, it was desirable to investigate the effect of this condition upon the design and execution of the work.

Mr. Cooper has stated that "during the early progress of the work it was an open secret that the Quebec Bridge Co. had but a small amount of money in sight."

In proof of this statement reference may be made to the following facts:

Between 1887 and 1898 the Quebec Bridge Co. accomplished practically nothing.

In 1900 it let the contract for the substructure, payment to be made partly out of subsidies and partly in bonds of the company, to be accepted at 60 per cent. of the face value, and offered its superstructure contract on similar terms.

In 1900 its securities were thoroughly investigated by the leading firms of American bankers, who declined to invest in them.

The Phoenix Bridge Co. was paid for the construction of the approach spans not by the Quebec Bridge Co., which ordered them, but by Mr. M. P. Davis.

It must have been clear to the engineers from the first that the financial conditions were such that nothing but absolutely necessary work could be undertaken.

The effect of the lack of funds is noticeable in the methods of calling for tenders, and of letting contracts, and in the delays that occurred in the execution of the work.

In September, 1898, the bridge contracting firms were asked to submit tenders upon their own designs, to be drawn in accordance with certain specifications. Practically this meant that each bridge company was asked to spend several thousand dollars on the preparation of plans, and that in return it was given an opportunity to bid for a contract to be let by a company of weak financial standing. The result was that, although the magnitude of the work placed it outside the limits of established practice, most of the tenders submitted were made from immature studies based upon insufficient data. The evidence shows that the Phoenix Bridge Co. gave more time and attention to the competition than any other tenderer, but the error afterwards made by it in assuming the weight of the structure for final designs shows how faulty the estimate accompanying its original tender was. We consider that the procedure adopted in calling for tenders was not satisfactory, in view of the magnitude of the work, and was not calculated to produce the most efficient results.

In his evidence Mr. Hoare ascribes the failure of the Quebec Bridge Co. to take advantage of the lump sum tender of the Phoenix Bridge Co. to lack of funds. We are satisfied from the knowledge gained during the designing of the 1,800-ft. span, that the 1,600-ft. span could not have been built with the weight of metal stated in the tender of March 1, 1899. Mr. Deans' letter to Mr. Hoare shows that the Phoenix Bridge Co. expected that its tender would be modified before the work was built. The letter is as follows:

(Personal and Private.) April 14, 1899.

Mr. E. A. Hoare,
Chief Engineer, Quebec Bridge Co.,
Quebec, Quebec.

Dear Mr. Hoare:

Mr. Szlapka and I were with Mr. Cooper the greater part of yesterday, and you will be glad to learn there was not a single vital or important criticism or mistake to be found in our plans. All the slight differences, such as dead load, anchor arms, reverse stresses, in one or two members, thickness of some detail plates, etc., were all thoroughly discussed and satisfactorily settled, and not a single one would *affect in any way our price or our proposition.* It was especially gratifying for us to learn this.

Mr. Cooper, however, somewhat upset me, by making the following remark, which, of course, I understood was entirely personal and without any full knowledge of the situation. He said: "Well, Deans, I believe that all of the bids will probably overrun the amount which the Quebec Bridge Co. can raise and that the result will be, as is usually the case, that all of the bids will be thrown out and a new tender asked on revised specifications and plans."

I told Mr. Cooper that, while this might be the usual procedure, that in the present case it was distinctly understood that whoever was the lowest bidder under the present specifications and plans would be awarded the work, and *if any modification were made their bid would be altered accordingly,* as this could readily be done through a conference with the bridge company's engineers and ourselves; as we could undoubtedly build as cheap a structure as any other company and that unless this plan was carried out as understood and agreed upon, the present bidders would be placed in a very unfair position after the expenditure of great time and expense.

I finally succeeded in convincing Mr. Cooper that this was the only fair method, but I think it will take the greatest care on your part to see that his report is not worded in such a way as to give the directors an opportunity of following this suggestion. Mr. Cooper undoubtedly desires to be perfectly fair, but, not having been through this whole matter like ourselves, does not fully understand the situation. I trust therefore that you will give his report the most careful scrutiny and get it in the right shape before it is submitted, as far as this suggestion is concerned. It would simply be just what our competitors, and particularly the Dominion Bridge Co., would like, or the Union Bridge Co., in fact, and I shall be much interested to hear from you on this point.

You have not advised me to whom I shall send the revised price, including delivery of the material from Quebec and Levis to site.

Mr. Lindenthal and I have an appointment with Mr. Cooper next Tuesday to discuss the suspension plan.

Kindly advise me when you will desire the revised propositions of the suspension design.

I remain,
Yours truly,
Jno. Sterling Deans.

We desire to draw attention to this letter, because it indicates that the contract was subsequently awarded on the result of this competition; the basis of the award being a lump sum tender, which could not have been accepted without modifications.

These errors we ascribe to failure on the part of the Quebec Bridge Co. to provide for sufficient preliminary studies of the project by its own engineers. It should also be noted that in the opinion of Mr. Cooper the preliminary surveys from which the main spans and the position of foundation piers, etc., were first determined were entirely insufficient; further examinations and borings were made on his advice and resulted in radical alterations in the design.

In April, 1900, the Phoenix Bridge Co. undertook to complete the plans for the bridge with all possible speed. In May, 1900, the Quebec Bridge Co., on the advice of its consulting engineer, determined to adopt a main span of 1,800 ft. and tacitly approved alterations of the specifications. The contractors were ordered to proceed with the designing for the 1,800-ft. span, under the supervision of Messrs. Hoare and Cooper, but the new specifications, which had to be accepted and officially approved by the Canadian Government, were not issued until the summer of 1903. This delay of three years seems to have occurred with the mutual consent of the Quebec Bridge Co. and the Phoenix Bridge Co. The Quebec Bridge Co. was not in a position to pay for the work and did not demand that the designing be proceeded with, nor did it furnish the necessary data for the designing. The Phoenix Bridge Co. was occupied with other contracts and did not make any further expenditures on behalf of the Quebec Bridge Co. until the financial position was assured.

When the Dominion Government finally came to be more closely identified with the Quebec Bridge Co., in 1903, it intimated unofficially to the Phoenix Bridge Co. its desire that the bridge should be ready for the Quebec Tercentenary, in 1908. For this and for ordinary business reasons the Phoenix Bridge Co. hurried the work of designing and manufacture as much as possible, this hurry resulting in errors, but not in those errors which were the immediate cause of the accident, these having been previously made. It is necessary in designing a bridge to commence by assuming what its weight will be, and as the design progresses to alter this assumption by calculation from the drawings. In the rush following the final financial arrangements of 1903, the necessity of revising the assumed weights was overlooked both by the engineers of the Phoenix Bridge Co. and by those of the Quebec Bridge Co., with the result that the bridge members would have been considerably overstressed after completion. This error was sufficient to have condemned the bridge had it not fallen owing to other causes.

During the period occupied in the development of the details of the design, the designing engineer and his staff were absorbed in the preparation of detail plans, and this resulted in the slighting of matters of primary importance.

Under the circumstances this condition was unavoidable, but could have been improved had the time between April, 1900, and August, 1903, been used in consideration and preparation of designs; however; business matters were in such shape that the Phoenix Bridge Co. were not warranted in expending time and money in this direction.

It is also proper to inquire whether the engineers modified their designs, to the injury of the bridge, on account of the financial conditions.

The importance of economy in the preparation of the first tenders is shown by the letter already quoted.

The tenders, however, had to conform to the original specifications, and there is no evidence of unwise economy in the provisions of these.

Mr. Cooper's attitude with regard to cost, while he was examining the plans and tenders, is shown by the following letter:

(Personal.) April 19, 1899.

E. A. HOARE, Esq.,
Chief Engr., Quebec Bridge Co.,
Quebec, Quebec.

DEAR MR. HOARE:

I spent most of yesterday in New York in consultation with Mr. Cooper and Mr. Lindenthal, and found that Mr. Cooper had no serious complaints to make in connection with Mr. Lindenthal's plan; in fact, he expressed himself as much interested in the ingenious design.

It developed, however, in conversation, and Mr. Cooper so expressed himself to Mr. Lindenthal, that, in view of the amount of the bid under his design, he would not give Mr. Lindenthal's plan careful and detailed consideration and would so report. This rather exasperated Mr. Lindenthal, and for a time I feared he might withdraw his bid, but it was smoothed over, and I think will be permitted to stand. Mr. Lindenthal thought that Mr. Cooper should report solely and wholly *on the merits of the several designs*, without any regard to cost, and each design should have the same careful consideration, and that you and your company alone should consider the question of price. I know this is entirely different from Mr. Cooper's instructions, and that it would be useless to spend detailed investigations upon plans which are very expensive in price, but Mr. Lindenthal viewed the matter from an engineer's standpoint, and, having taken such unusual pains with the design and estimate, felt that he was in a measure being slighted.

Mr. Cooper advises that he will finish about May 1.

I think it of the utmost importance to see you some time before that date, and write to ask if you will not come to New York. Cooper also advised me that he had no authority to receive any revised bids for possible reduction in suspension bridge wire, and I think this entirely proper. It seems to me, however, *that you should have all of these bids in your hands at once*, and *I will be prepared to submit ours when you come to New York.*

Please let me know at once and by *wire* when you will be in New York.

Yours truly,
JNO. STERLING DEANS,
Chief Engineer.

In his report upon the competitive tenders submitted on June 23, 1899, Mr. Cooper says:

"The tender accompanying this plan (from the Phoenix Bridge Co.) is the lowest in price and is the most favorable as to prospective duties upon the materials to be used in its construction. I therefore hereby conclude and report that the cantilever superstructure plan of the Phoenix Bridge Co. is the "best and cheapest" plan and proposal of those submitted to me for examination and report."

There is no evidence whatever to indicate that economy at the expense of efficiency was ever considered by Mr. Cooper. His award was made distinctly to the lowest tenderer and he so states, but in the preceding paragraphs the accepted design is stated to be "an exceedingly creditable plan" and "in accordance with your specifications."

The full text of the report and Mr. Cooper's evidence show that his award was made for technical reasons, although he did not overlook costs; and he states that he was left absolutely unhampered in any manner in his report as to which he should consider the best plan and the best bridge.

In a memorandum accompanying his original report Mr. Cooper indicated his desire to alter the specifications and to reconsider the length of the main span as soon as proper foundation surveys could be made.

These changes were subsequently made, but it does not appear that economy was the ruling factor in his selections. He unquestionably increased the unit stresses, but not to a point beyond those already adopted by the Bridge Department of the City of New York for its great bridges, and the increase can be stated to be in harmony with the most advanced practice of that time and due more to an instinct of wise investment than to any endeavor to simply cheapen the structure. The wisdom of his modifications is discussed in Appendix 18.

In his evidence Mr. Cooper has outlined his intentions in making his alterations, and a desire not to involve the Quebec Bridge Co. in a greater expenditure than was at first anticipated is given among them; but on the same page it is sharply stated that he would not recommend any plans that did not promise to give a safe and satisfactory structure.

The facts that have been discussed in this appendix show that, while there is no evidence of any cheap and insufficient work being purposely done by either Mr. Cooper or the Phoenix Bridge Co., there is evidence to prove that the financial weakness of the Quebec Bridge Co. seriously interfered with the carrying out of the undertaking.

The Phoenix Bridge Co. were limited only by the specifications as amended by Mr. Cooper, endorsed by the government and concurred in by themselves, and no sum of money or total weight was set as a limit in the designing or building of the superstructure, the sole aim of all being to produce a safe and economical bridge.

The Phoenix Bridge Company were paid for the work at so much per pound, so there was no incentive to the Phoenix Bridge Co. to make the bridge lighter than they deemed it should be.

(Signed) HENRY HOLGATE, Chairman;
J. G. G. KERRY,
J. GALBRAITH.

APPENDIX 6.—THE HISTORY OF THE DEVELOPMENT OF THE SPECIFICATIONS AND A DISCUSSION OF THE EVIDENCE RELATING TO IT.

During the summer of 1898, Mr. E. A. Hoare, acting in his capacity of chief engineer of the Quebec Bridge Co., prepared the first set of specifications for the construction of the bridge. On July 2, 1898, Mr. Hoare was instructed by resolution of the board of directors of his company to communicate with Mr. Collingwood Schreiber, the deputy minister and chief engineer of the Department of Railways and Canals, so that a set of specifications would be secured that would be satisfactory both to the government and to the Quebec Bridge Co. On direction of Mr. Schreiber, Mr. Hoare submitted his draft specifications to Mr. R. C. Douglas, the bridge engineer of the department, for criticism.

Mr. Douglas states in his evidence that he read over the specifications with Mr. Hoare, but did not suggest any alterations in them, because Mr. Hoare met his objections by explaining that the specifications would be used only in connection with preliminary competitive tenders and not for the construction of the bridge. He made no official report upon them.

These specifications are, as stated by Mr. Douglas, mainly a direct copy from the general specifications for steel and iron bridges issued by the Department of Railways and Canals in 1896. An examination bears out Mr. Cooper's statement that they were not drawn by anyone having the magnitude of this bridge structure in his mind.

On Aug. 31, 1898, Mr. Schreiber, by letter, notified the Quebec Bridge Co. that Mr. Hoare's specifications had been approved.

They were printed on order of the Quebec Bridge Co. over date of Sept. 1, 1898, and a copy of them was sent out with each of the invitations to tender mailed to bridge contractors in September, 1898.

On Nov. 12, 1900, a subsidy agreement, No. 13988, was made between the Government of Canada and the Quebec Bridge Co., by which, on certain conditions, assistance to the amount of $1,000,000 was promised to the Quebec Bridge Co. The Hoare specifications were made a part of this agreement with one alteration, viz.: the length of the main span was made 1,800 feet instead of 1,600 feet, the Quebec Bridge Co. having officially decided on the longer span on May 5, 1900. There is no evidence to show that these specifications were reconsidered at this time by the technical advisers of the government.

The original specifications were not used in the design of the approach spans which was made in 1901-2, alterations being made to meet the wishes of Mr. Douglas, whose approval was required by the deputy minister and chief engineer before payments on subsidy account could be authorized.

Mr. Cooper, in a memorandum accompanying his original report of June 23, 1899, indicated that he thought the specifications could be modified with considerable advantage to the interests of the company. On May 1, 1900, Mr. Cooper recommended to the company the adoption of the 1,800-ft. main span, his recommendation being dependent upon the use of certain alterations in the specifications which were, in his opinion, desirable and justifiable. In a letter of even date to the Hon. S. N. Parent he suggests that he "be instructed to make such modifications in the adopted competitive plan when adapted to the new lengths, as may tend to reduce the cost without reducing the carrying capacity or the stability of the structure."

On May 6, 1900, the board of directors of the Quebec Bridge Co. directed its engineers (Messrs. Cooper and Hoare) to instruct the contractors (The Phoenix Bridge Co.) to prepare plans using the 1,800-ft. span recommended by Mr. Cooper. No active effort was made by the officials of either company to carry out these instructions, and the amendments to the specifications, which had to be formally approved by the government before the plans could be commenced, were not actively discussed until May, 1903. The delay was due to financial reasons, no one knowing when the work would proceed.

The National Transcontinental Ry. project, which was made public in the spring of 1903, was so planned that a bridge near Quebec would be a national necessity and legislation involving a guarantee by the government of the securities of the Quebec Bridge Co. was proposed. With the improved financial outlook, the activity of the engineers and contractors was renewed. Mr. Cooper prepared his amendments to the original specifications and sent them to Mr. Szlapka, the designing engineer of the Phoenix Bridge Co., for his information and criticism. Mr. Szlapka criticised the draft and returned it to Mr. Cooper, after having taken a copy of it, on May 20, 1903. The comments in his letter show that he had carefully considered the purport of the amendments. Mr. Deans, returning from Ottawa, wrote to Mr. Cooper on May 22, 1903, as follows: "I was requested by the Ottawa officials to urge upon you to act as promptly as possible in the matter of completing the specifications and to forward the same to Mr. Hoare without delay. There is urgent necessity of their taking prompt action."

On May 28, 1903, Mr. Deans wrote to Mr. Cooper suggesting some alterations in his draft for the amendments, one of which appears in the preface to Mr. Cooper's draft of June 2, 1903. Mr. Cooper completed his draft of the amendments and forwarded it to Mr. Hoare, accompanied by a memorandum dated June 2, 1903. A copy of the papers was sent also to Mr. Deans.

Mr. Deans, under date of June 4, 1903, acknowledged the receipt of these papers and expressed the hope that "we will soon hear that these specifications have been approved by the government."

On June 16, 1903, Mr. Szlapka, at the request of Mr. Deans, sent to Mr. Hoare two sheets of calculations comparing the stresses permitted under the Hoare specifications with those permitted by the Cooper amendments. In the accompanying letter he stated: "With figures given I hope you will be able to see that the difference between the two specifications is very immaterial. Where the new specifications give smaller sections than your specifications, it will be found during actual final computations that, owing to the magnitude of the structure and consequently the very large dead load, as compared with the live load, the unit stresses selected are fully justified." On the sheets accompanying this letter the amendments are referred to as the "Proposed Specifications of June, 1903. (Theo. Cooper and Phoenix Bridge Co.)" The officials of the Quebec Bridge Co. were therefore distinctly advised that both Mr. Cooper and the engineers of the Phoenix Bridge Co. considered the adoption of the amendments entirely desirable.

Owing to the terms of the subsidy agreement of Nov. 12, 1900, it was necessary to have these amendments approved by the government, and they were accordingly transmitted to Mr. Schreiber by the Quebec Bridge Co. Mr. Schreiber handed the papers to Mr. Douglas for report shortly after they reached his office, and on July 9, 1903, Mr. Douglas made his report in writing. In it he advised the adoption of many of Mr. Cooper's suggestions, but criticised the high unit stresses that were proposed and the suggestion made in the memorandum as to using the bridge for heavier rolling loads than those specified in the amendments. He also advised that the Quebec Bridge Co. be required to submit new specifications and not merely amendments to the approved Hoare specifications.

Mr. Douglas' opposition was evidently anticipated, as will be seen by a letter from Mr. Hoare quoted in the evidence. On receipt of the report of July 9, 1903, Mr. Schreiber had to decide whether he would depend upon Mr. Cooper or upon Mr. Douglas for technical advice, and evidently decided in favor of the former, for, as stated in the evidence, Mr. Douglas from that date had no authoritative connection with the undertaking.

Mr. Cooper's intention in making these amendments was, as stated in the evidence, to rearrange the wind and live loadings so that they would more nearly correspond to his own prediction of the actual loadings that would come upon the structure; and, accordingly, he decreased the wind load and increased the rolling live load. He was also of the opinion that the maximum stresses might safely be increased, and had recommended the 1,800-ft. span on the assumption that this increase would be permitted. He was throughout impressed with the necessity of making his changes without adding to the financial demands on the resources of the company.

Mr. Schreiber's views are stated in a letter to Mr. Cooper under date of July, 1903, which reads as follows:

"I have received from Mr. E. A. Hoare two memoranda made by you in respect of the plans of the superstructure of the Quebec bridge, suggesting certain modifications which you consider desirable.

"Inasmuch as the contract for this structure contains an express specification by which I am bound, I am unable, as matters stand, to sanction any deviation from it.

"I am, however, strongly impressed with the expediency, in order not to hinder the progress of the work of manufacture, of permitting you certain latitude in the preparation of the detail plans, even to the extent of adopting (with my own concurrence) such modifications as may appear proper; and, holding this view, I have asked that authority be given me by Order-in-Council which will enable me to act in that direction.

"Nothing can, of course, be done until such order is passed, but on receipt of it I will communicate with you immediately."

Mr. Schreiber communicated with the Minister of Railways and Canals, as indicated in the foregoing letter, on July 9, 1903, and his recommendations were transmitted by the Minister to Council on July 18, 1903, and form the substance of the Order-in-Council of July 21, 1903. This order reads as follows:

"Extract from a Report of the Committee of the Honorable the Privy Council, Approved by the Governor-General on July 21, 1903.

"On a memorandum dated July 18, 1903, from the Minister of Railways and Canals, representing that a communication has been received from the chief engineer of the Department of Railways and Canals, in regard of the bridge across the River St. Lawrence, near Quebec, now in course of construction, reading as follows:

"Office of the Deputy Minister and Chief Engineer,
"Ottawa, Ont., July 9, 1903.

"Sir—Certain questions are at present under consideration and discussion between Mr. Theodore Cooper, the consulting engineer of the Quebec Bridge Co., and myself, involving the expediency of adopting some slight modifications of the specification for the superstructure of the bridge across the St. Lawrence River, now in course of construction by that company, attached to the subsidy contract made with them; Mr. Cooper having prepared detailed plans and specifications of such superstructure which call for special consideration.

"Mr. Cooper is a bridge engineer of high standing in New York, and a man of repute and reliability. He has made a very careful study of the necessities of this superstructure, which, I may say, was especially imperative in view of the unusual magnitude of the span and of the general design of the work. His modifications may therefore reasonably be considered to be in the best interests of the work, and being engaged continuously upon the work during construction Mr. Cooper will be in the best position to note the requirements of the structure as the work progresses.

"In a work of this character and magnitude it is highly important that no delay should arise from causes not absolutely unavoidable, to hinder the steady prosecution of construction, and there is reason to believe that the company require immediate instructions to proceed.

"In connection with the foregoing, I would suggest that the department be authorized to employ a competent bridge engineer to examine from time to time the detailed drawings of each part of the bridge as prepared, and to approve of or correct them as to him may seem necessary, submitting them for final acceptance to the chief engineer of railways and canals.

"I have the honor to be, sir, your obedient servant,
(Signed) "Collingwood Schreiber,
"Chief Engineer.

"To L. K. Jones, Esq., Secy. Dept. Rys. and Canals. Ottawa."

"The minister, recognizing the point urged by the chief engineer that there should be no hindrance thrown in the way of the parties engaged in the construction of the bridge superstructure, and considering that, under the circumstances, the course suggested by him is the best that could be adopted for the avoidance of delay, recommends that authority be given for leaving the matter in the hands of the chief engineer to the extent expressed in his communication, it to be understood that any action taken under his authority in respect of the said bridge shall be regarded and treated as in no way a violation of the company's subsidy contract dated Nov. 12, 1900, which contract, if carried out in accordance with the decisions of the chief engineer and to his satisfaction, shall be deemed to have been properly fulfilled.

"The committee submit the same for approval.
"John J. McGee,
"Clerk of the Privy Council."

Mr. Schreiber's principal recommendation was "that the department be authorized to employ a competent bridge engineer to examine from time to time the detail drawings of each part of the bridge as prepared, and to approve of or correct them as to him may seem necessary, submitting them for final acceptance to the chief engineer of railways and canals." In other words, it was his intention to place the final control of the bridge construction in the hands of a specially chosen bridge expert who would be an employee of the department, and who would report directly to the deputy minister. As soon as the Order-in-Council was passed, inquiry was commenced for a suitable engineer.

The policy of Mr. Schreiber was not in accord with the wishes of the Quebec Bridge Co. and its associates, and as soon as Mr. Cooper fully understood the deputy minister's plans he protested vigorously. His position is very clearly set forth in the following letter:

"New York, July 31, 1903.

"Dear Mr. Hoare:

"I am in receipt of papers from Mr. Schreiber which surprise me. He is to select an engineer in New York who will examine from time to time the plans, approve or correct the same as to him may seem necessary, etc.

"This puts me in the position of a subordinate, which I cannot accept.

"It does not relieve the situation a bit. Such an engineer must either be given liberty to do what he thinks best or he must have the very instructions which I have sought, stating to what extent there may be modifications from the original specifications, if any are to be allowed.

"In either case he becomes the engineer in whom trust and confidence are reposed.

"It seems to me a very simple matter for the chief engineer of railways and canals to decide that the 'original specifications must be rigidly carried out,' or that 'certain modifications are approved,' or that 'the company has perfect liberty to carry out the work to the best advantage, provided the efficiency of the original contract be not reduced'—I would then know where I stand.

"Yours truly,
(Signed) "Theodore Cooper."

"I have written to Mr. Schreiber that I do not see how such an engineer could facilitate the progress of the work or allow me to take any responsible steps independently of his consent."

On July 30, 1903, Mr. Cooper wrote to Mr. Deans advising him of Mr. Schreiber's programme and Mr. Deans intervened actively. The following letters show very clearly that the Phoenix Bridge Co. heartily supported Mr. Cooper in his contention and that the Quebec Bridge Co. was in full sympathy with their views:

"July 31, 1903.

"E. A. Hoare, Esq.,
"Chief Engineer, Quebec Bridge Co.,
"Quebec, Canada.

"Dear Mr. Hoare:

"I was greatly exercised this morning upon receiving a letter from Mr. Cooper, under date of July 30, stating that he had received from Mr. Schreiber copy of the Order-in-Council and also a letter from Mr. Schreiber. In this letter Mr. Schreiber states that he has asked for authority to employ a competent bridge engineer to examine from time to time the detail drawings of each part of the bridge as prepared and to *approve of or correct them* as to him may seem necessary, *submitting these for final acceptance* to the chief engineer of railways and canals. Mr. Schreiber further says: 'I have not yet named *an engineer in New York to consult with you*, but will do so without unnecessary delay, and in the meantime I think you may safely go to work on the plans.'

"The seriousness of this action I have not the least doubt you will appreciate immediately. It leaves the entire matter 'up in the air' and much worse than the condition we were all trying to avoid—which was to save most important time, and that when Cooper once approved our designs and details it would be final and accepted by the department. This is why I understand you secured the Order-in-Council. It practically brings all matters to a standstill, as neither Mr. Cooper or ourselves would know where we stand until this new hand could be consulted with, and even then we would only know as each plan was passed upon.

"I cannot impress upon you too strongly the necessity of taking immediate action to stop any such plan as suggested by Mr. Schreiber.

"When you consider that the entire feeling and action of Mr. Cooper's was to save the Quebec Bridge Co. needless expense, without the least sacrifice in the design or efficiency of the structure, it has certainly proven a thankless task for all concerned, and unless this present action upon Mr. Schreiber's part is immediately stopped the entire business will be in a worse condition than if it had been let entirely alone.

"I am trying to reach you by 'phone, as I appreciate the necessity of immediate action.

"Yours truly,
(Signed) "Jno. Sterling Deans,
"Chief Engineer."

"Phoenixville, Pa., July 31, 1903.

"Theodore Cooper, Esq.,
"Consulting Engineer,
"35 Broadway, New York, N. Y.

"Dear Mr. Cooper:

"To say that I was surprised by the contents of your letter of July 30 is putting it mildly. I am trying to reach Mr. Hoare by 'phone. In addition, I have wired him and also written a strong letter expressing my feeling in the matter.

"The suggested action by Mr. Schreiber would place the business in a much worse condition than it was originally in. The 'Order-in-Council' was taken solely to save time and to have your approval of our details final and binding on the government—it simply being necessary to have Mr. Schreiber's signature as a matter of form. It has certainly proven to be a thankless task so far, in trying to save the Quebec Bridge Co. a large amount of money, without in the least affecting the efficiency of the structure.

"We, of course, agree with you that we are at a standstill until this matter is settled, as certainly the matter of a new engineer is an uncertain quantity at present.

"I cannot but believe that a trip to Quebec by yourself and myself would tend to clear the situation.

"Yours truly,
(Signed) "Jno. Sterling Deans,
"Chief Engineer."

"Phoenixville, Pa., Aug. 1, 1903.

"Mr. Theo. Cooper, C. E.,
"35 Broadway, New York, N. Y.

"Dear Mr. Cooper:

"I talked with Mr. Hoare over the 'phone yesterday (the service was not very satisfactory), and also wired him two long messages, and have received his reply stating that 'he will take up the question with parties at Ottawa and that he would go ahead, and if anything turns up to cause trouble *tell Cooper to let me know at once*.' I have written him again and urged him to stop entirely this proposed plan and explaining that the sole purpose of the Order-in-Council was to give you the final authority to settle all details, the government approval being a mere formality, and in this way save time which was so valuable. I personally think it would have been much better to have had Douglas, as originally proposed, rather than to have the present plan carried out; but we must insist upon having the whole matter stopped.

"Yours truly,
(Signed) "Jno. Sterling Deans,
"Chief Engineer."

(Telegram.) "Aug. 3, 1903.

"E. A. Hoare, Chief Engineer,
"Quebec On (Bridge) Co.,
"Quebec, Canada.

"I found Cooper had written and wired you and feels much more strongly than I do the serious result of any such action. It would be disastrous to have proposed appointment finally made. You and I should see Schreiber in Ottawa at once and come to some better understanding. As it now stands nothing can be done on plans. Answer to Phoenixville.

(Signed) "Jno. Sterling Deans."

Mr. Cooper went to Ottawa and discussed the situation with Mr. Schreiber, who, as a result of this conference, made a further recommendation to the minister under date of Aug. 13, 1903. This recommendation is embodied in the Order-in-Council passed on Aug. 15, 1903.

The text of this Order-in-Council is as follows:

"Extract from a Report of a Committee of the Honorable the Privy Council, Approved by His Excellency on Aug. 15, 1903.

"On a memorandum dated Aug. 13, 1903, from the minister of railways and canals, representing that by an Order-in-Council of July 21, 1903, authority was given, in accordance with a suggestion made by the chief engineer of the Department of Railways and Canals, for the employment of a competent bridge engineer to examine, from time to time, detail drawings of the superstructure of the bridge across the River St. Lawrence, near Quebec, now in course of construction, in view of certain modifications suggested by the consulting engineer of the bridge company; the said plans to be submitted, for final acceptance, to the chief engineer of the Department of Railways and Canals.

"The minister further represents that the chief engineer has this day reported, stating that, as the result of the personal interview had with the company's consulting engineer, he would advise that, provided the efficiency of the structure be fully maintained up to that defined in the original specifications attached to the company's contract, the new loadings proposed by their consulting engineer be accepted; all detail parts of the structure to be, however, as efficient for their particular function as the main members for theirs, the efficiency of all such details to be determined by the principles governing the best modern practice, and by the experience gained through actual test; all plans to be submitted to the chief engineer, and until his approval has been given, not to be adopted for the work.

"The minister recommends that authority be given for following the course so advised by the chief engineer, the Order-in-Council of July 21 last to be modified accordingly.

"The committee submit the same for approval.

"John J. McGee,
"Clerk of the Privy Council."

Mr. Cooper's interpretation of the Order-in-Council of Aug. 15 was that it gave him an absolutely free hand, provided efficiency was maintained up to the standard of the specifications attached to the subsidy contract.

Necessarily throughout the development of the design of the structure cases would arise when further modifications of the written specifications would appear desirable. Such cases did arise, and were met from time to time by Mr. Cooper. In such cases he proceeded according to his interpretation of the Order-in-Council, and did not submit further opinions to the government engineers for approval.

In this connection, Mr. Schreiber differs from Mr. Cooper, as the following extract from his evidence shows:

Q. Considering the relation of Mr. Cooper to the Quebec Bridge & Railway Co. and your opinion of Mr. Cooper's ability and the relation of the government with the Quebec Bridge & Railway Co., would you consider that Mr. Cooper would have the power or authority to amend the specifications for the work from time to time as he might consider necessary or desirable, and would those amendments be tacitly accepted by all parties concerned?

A. (Mr. Schreiber) No, I think not. They would have to be submitted to me and they would come before our bridge engineer—before the bridge engineer of the Department of Railways and Canals—before they would be accepted.

Q. So that, unless we can find a formal acceptance of the changes or alterations made in the specifications, we would have to consider them as unauthorized?

A. (Mr. Schreiber) Certainly.

There is, however, no evidence to show that Mr. Schreiber even questioned any decision made by Mr. Cooper or in any way interfered with him. We consider that in this Mr. Cooper was acting, as he believed, in the best interests of the work.

A copy of the Order-in-Council was sent to the Phoenix Bridge Co., so they were aware of its conditions, one of which was, "all plans to be submitted to the chief engineer (Mr. Schreiber), and until his approval has been given not to be adopted for the work." This condition also was embodied in explicit form in the contract between the Phoenix Bridge Co. and the Quebec Bridge Co., and yet, the engineer of the Phoenix Bridge Co., when asked, "Did you consider the approval of the plans by the Department of Railways and Canals a condition precedent to the fabrication of the bridge," answered "No."

The specifications thus officially amended by authority of Order-in-Council were transmitted to the Phoenix Bridge Co. When asked, "Did you fully concur in all the amendments made in the specifications, having in mind that you were endeavoring to produce the best possible bridge," Mr. Szlapka, the designing engineer of the Phoenix Bridge Co., answered, "The amendments made in the specifications by Mr. Cooper were not subject to my approval."

The action of Mr. Schreiber at this time and subsequently can only be explained on the assumption that he considered the Order-in-Council of Aug. 15, 1903, to be a direction to him to place the responsibility for the building of the bridge entirely in Mr. Cooper's hands. Mr. Cooper's amendments were, according to Mr. Douglas' evidence, accepted and used by the department in subsequent examinations of plans, and Mr. Cooper's signature was considered by the department practically as a final warrant of the sufficiency of the plans.

That the proceedings of the department were irregular and that Mr. Cooper was assuming a degree of authority not in keeping with the wording of the Order-in-Council of Aug. 15, 1903, was clear to the Quebec Bridge Co., as the following letter shows:

"Quebec, May 27, 1907.

"J. S. Deans, Esq.,
"Chief Engineer Phoenix Bridge Co.,
"Phoenixville, Pa.

"Dear Sir:

"In reply to your letter of the 24th inst., I am aware that you are doing everything that is possible to hasten the forwarding of the plans for approval by the government, except that much time might have been saved if Mr. Cooper had signed the tracings, instead of having to sign so many blue prints.

"The signature of the consulting engineer does not comply with the government regulations. The Order-in-Council passed some years ago only authorized certain modifications in the specification and details from time to time, if found necessary. The obligations under contracts with the company and the government still remaining, viz.: that no work is to be proceeded with or estimates paid until the final plans have been passed through the various stages required by the government in the Department of Railways and Canals. This is the point they are objecting to. Understand that it is not myself that is raising any question, but I am only endeavoring to bring you to line with the contracts. The government has passed no Order-in-Council cancelling your obligation to have all your plans approved at Ottawa before any metal is fabricated. We are under very close investigation now.

"Yours truly,
(Signed) "E. A. Hoare."

It should be stated that the Quebec Bridge & Ry. Co. was throughout fully advised of what was being done in New York and Phoenixville and did not make any objection to the authority assumed by Mr. Cooper or to the acceptance of that authority by the Phoenix Bridge Co., notwithstanding provision to the contrary existing in the contract. This letter also indicates a more active supervision on the part of the government than had previously been exercised.

The Phoenix Bridge Co. was immediately advised of the terms of the Order-in-Council of Aug. 15, 1903, but being fully aware of the arguments and influences that had brought about the enactment of that order, they concluded that it was intended to grant exactly what Hon. S. N. Parent had asked for in his letter of June 29, 1903.

Mr. Deans and Mr. Szlapka in their evidence make it very clear that they considered Mr. Cooper's pronouncements final and not liable to alteration either by the Quebec Bridge & Ry. Co. or by the Dominion Government.

In the opinion of the Commission it is always desirable, when an entirely novel problem is to be solved, to have the advice of several engineers upon the unproven features of the design before attempting to execute it. Having accepted the government's decision to depend upon the advice of only one man, the authorities acted therefore in accordance with the best knowledge of the time; and the most competent engineers would have endorsed the concentration of responsibility upon the most experienced and able man.

In effect, after Aug. 15, 1903, instructions given by Mr. Theodore Cooper from time to time were the specifications. In the offices of the Phoenix Bridge Co. and in the works of the Phoenix Iron Co. the Hoare specifications as amended by Mr. Cooper were recognized as official and were so used. (See evidence, Page 945 and Exhibits 99, 100, 101 and 102.) It was recognized by these companies that Mr. Cooper had authority to alter any requirements of the specifications, and it is in evidence that this authority was not infrequently exercised.

(Signed) Henry Holgate,
Chairman.
J. G. G. Kerry,
J. Galbraith.

APPENDIX 7.—A DESCRIPTION OF THE ORGANIZATION AND STAFFS MAINTAINED BY THE DIFFERENT CORPORATIONS INTERESTED IN THE ERECTION OF THE BRIDGE.

There were four parties directly interested in the building of the bridge, viz.: The Canadian Government, the Quebec Bridge & Railway Co., the Phoenix Bridge Co., and the Phoenix Iron Co. Each had its own staff to take charge of the portions of the work in which it was interested.

The Commissioners made the personal acquaintance of all the senior officials concerned, and discussed with each of them the duties he was called upon to perform. Evidence has been secured giving the previous experience of these men, their fitness for their several positions, and their duties.

The Dominion Government was represented by the Deputy Minister of the Department of Railways and Canals and his assistants; two Deputy Ministers and three Inspectors having been connected with the work.

The Government's interests are set forth clearly in the Subsidy Agreement of Nov. 12, 1900, and in the Guarantee Act of 1903, and throughout the work the Quebec Bridge & Railway Co. recognized its obligations to the Government by requiring its contractors to do their work in such a manner, that it would be acceptable to the Government.

Although the Deputy Minister of the Department was charged with the duty of examining the plans and specifications, all of which were subject to his approval, checking up the monthly estimates which were the basis for payments and exercising general oversight of the work up to the time of its final acceptance, in reality the whole responsibility for specifications, plans and construction was upon the officials of the Quebec Bridge & Railway Co., its interests being identical with those of the Government, Mr. Cooper's special qualifications having been officially recognized in the Orders-in-Council of July 21 and August 15, 1903.

The issue at the time previous to the passing of the Order-in-Council of August 15, referred to, was whether Mr. Cooper's approvals were to be subject to cancellation on the advice of an expert engineer employed by the department or not. By the Order-in-Council of Aug. 15, 1903, the Government practically decided that Mr. Cooper's decisions were to be final, and neither Mr. Schreiber nor his successor, Mr. Butler, at any time interfered with his control of the technical features of the undertaking. Mr. Cooper's understanding of the situation was the same, and this indicates clearly both the Government's position and that of Mr. Cooper on this question.

The Quebec Bridge & Railway Co. maintained in its service and employed on the work a chief engineer, a consulting engineer, two erection inspectors and four mill and shop inspectors. The Chief Engineer, Mr. E. A. Hoare, M. Inst. C. E., had an extensive experience as a railway engineer, and had done most of the company's preliminary work. The record of his professional experience will be found in full in his evidence. Mr. Hoare had a high reputation for integrity, good judgment and devotion to duty. From the standpoints of personal character and knowledge of Quebec and its people, no better man could have been found, and the evidence throughout shows that to the best of his ability the company was faithfully served. There is, however, nothing in Mr. Hoare's record that would indicate that he had the technical knowledge to direct the work in all of its branches.

The company's directors do not seem to have realized the importance of the duties pertaining to Mr. Hoare's position, and while believing that he was not competent to control the work they still gave him the position, the powers and emoluments of the office of chief engineer.

While we can only consider this as a mistake on the part of the Quebec Bridge & Railway Co., yet we regret to say that such appointments are by no means uncommon, and it must be recognized that in many cases good executive ability is valued more highly or considered of more importance than special professional knowledge.

Mr. Hoare personally considered that he was in general control of the construction and that everything was under his jurisdiction except the approval of plans; the evidence shows that he gave much personal time to the oversight of the fabrication of the material, to inspection of the erection and the preparation of the estimates; it also shows that he lacked a comprehensive grasp of the work that was being done by the inspectors and that although his subordinates entertained the highest personal regard for him they did not look to him for advice when technical difficulties arose.

Mr. Theodore Cooper, of New York, was the consulting engineer. In the extent of his experience and in reputation for integrity, professional judgment and acumen, Mr. Cooper had few equals on this continent, and his appointment would have been generally approved. Mr. Cooper's strict duties were to examine, correct and approve the plans prepared by the contractors and to give engineering advice to Mr. Hoare when requested. Mr. Cooper and his chief assistant, Mr. Bernt Berger, carried on a most thorough and painstaking examination of the plans. Mr. Cooper appointed both shop and erection inspectors for reasons explained in his evidence, and had these inspectors report fully and regularly to him. Mr. Cooper states that he greatly desired to build this bridge as his final work, and he gave it careful attention. His professional standing was so high that his appointment left no further anxiety about the outcome in the minds of all most closely concerned. As the event proved, his connection with the work produced in general a false feeling of security. His approval of any plan was considered by everyone to be final, and he has accepted absolute responsibility for the two great engineering changes that were made during the progress of the work—the lengthening of the main span and the changes in the specification and the adopted unit stresses. In considering Mr. Cooper's part in this undertaking, it should be remembered that he was an elderly man, rapidly approaching seventy, and of such infirm health that he was only rarely permitted to leave New York.

Mr. Cooper assumed a position of great responsibility and agreed to accept an inadequate salary for his services. No provision was made by the Quebec Bridge Co. for a staff to assist him, nor is there any evidence to show that he asked for the appointment of such a staff. He endeavored to maintain the necessary assistants out of his own salary, which was itself too small for his personal services, and he did a great deal of detail work which could have been satisfactorily done by a junior. The result of this was that he had no time to investigate the soundness of the data and theories which were being used in the designing and consequently allowed fundamental errors to pass by him unchallenged. The detection and correction of these fundamental errors is a distinctive duty of the consulting engineer, and we are compelled to recognize that in undertaking to do this work without sufficient staff or sufficient remuneration, both he and his employers are to blame, but it lay with himself to demand that these matters be remedied.

During the construction of the substructure, Mr. Cooper visited the bridge site on several occasions, but did not visit the bridge during the erection of the superstructure. He visited the Phoenix Iron Co.'s shops but three times during the fabrication of the structure.

During erection, Mr. Cooper, upon receipt of information from Mr. McLure, ordered certain work on the erection to be stopped for correction; this order was communicated by him to Mr. Hoare, who stopped the work accordingly.

In the sense that the inspectors looked to Mr. Cooper for advice and directions, almost entirely, and that he appointed them and issued instructions to them, and also that he dealt directly with the contractors, he assumed many of the duties of a chief engineer; owing to the special nature of the work, he was the only one in the employment of the Quebec Bridge Co. who was capable of assuming these duties. He was not authorized to act in this capacity, nor was he able to visit the bridge during its erection.

Norman R. McLure was an inspector assisting Mr. Edwards in the shops up to the beginning of erection, when he acted as inspector of erection, being employed during the winter as an inspector in the shops. He was appointed by Mr. Cooper, with Mr. Hoare's concurrence. He was responsible to both Mr. Cooper and Mr. Hoare, and received instructions from both, but reported to Mr. Hoare principally upon matters regarding monthly estimates, and to Mr. Cooper upon matters of construction. Mr. McLure had definite instructions in writing as to duties from Mr. Cooper, but had none from Mr. Hoare. Mr. McLure is a technical man, a graduate of Princeton University (1904), and previous to the Quebec bridge work was inspector of bridges for the New York, Ontario & Western Ry., and in so far as his experience fitted him, performed his duties well and is a painstaking and capable engineer. He had not full authority on the work, and depended on Mr. Cooper for all technical advice and instructions.

We are at a loss to understand why Mr. Cooper, under the circumstances, did not place a more experienced man in full local charge of the inspection of erection. We must recognize, however, that the power of making such an appointment did not rest with Mr. Cooper, and that Mr. Hoare had stated in evidence his conviction of his own ability to handle the work.

Mr. E. R. Kinloch acted as inspector of workmanship throughout erection, having been appointed by Mr. Hoare and was responsible to him. Mr. Kinloch's experience on bridge work, as given in his evidence, shows that while without technical training he had been connected with the building of several heavy structures and was thoroughly capable of handling ordinary bridge erection. His duties were to watch the structure closely, and to see that the erection work, and particularly the rivetting, were properly done and in accordance with the instructions issued by the Phoenix Bridge Co. While the Phoenix Bridge Co. did not recognize his authority, they co-operated cordially with him to the common end of endeavoring to obtain good work. Mr. McLure and Mr. Kinloch worked independently, but all Mr. Kinloch's observations and criticisms were reported to Mr. McLure, and these have added a great deal to the value of these records. Mr. Kinloch was thoroughly at home in his work, and executed his duties carefully and intelligently. He appears from the evidence to have been a keen observer and fully impressed with the importance of his duties. We are, however, convinced that the bridge was too large for one man to thoroughly cover in detail all the work that was entrusted to Mr. Kinloch, and that there should have been more inspectors of equal ability.

Mr. E. L. Edwards was chief inspector of shop work, and was appointed by Mr. Cooper, with the approval of Mr. Hoare. He reported to both Mr. Cooper and Mr. Hoare. The circumstances of his appointment are stated by Mr. Cooper in his evidence and Mr. Edwards' experience as an inspector is given in full in his own evidence. His duties were to see that the metal supplied by the rolling mills came fully up to requirements of the specifications, and that it was properly tested; he sent the test reports regularly to Mr. Hoare, and visited Mr. Cooper for instructions every month, or when anything irregular happened. He had also to see that the finished members corresponded in dimensions exactly with the approved plans, and that the methods of fabrication that were used were in each case most accurate and satisfactory. The test records and the list of shop errors detected by the inspectors are evidence as to how Mr. Edwards performed his duties.

Mr. I. W. Meeser was Mr. Edward's assistant and his inspection was more particularly directed to the shopwork. He had ample experience in shopwork, having been trained as a machinist, and was at one time sub-foreman in the shops of the Phoenix Iron Co. The commissioners satisfied themselves during their visit to Phoenixville that both Mr. Edwards and Mr. Meeser thoroughly understood the work they had undertaken. The commissioners are not, however, satisfied that the shop inspection as arranged for by the Quebec Bridge & Ry. Co. would have been as thorough as it was if it had not been aided throughout by the hearty co-operation of the officials of the Phoenix Bridge Co. and of the Phoenix Iron Co. The staff was too small; and it is our opinion that the Quebec Bridge Co. would have shown better judgment had it employed a larger staff under the direction of an independent man of wider technical knowledge and who would have been sufficiently forceful to hold his own against the contractors.

Messrs. Keenan and Ostrom acted as inspectors in the rolling mills at Harrisburg and Pittsburg, respectively. There is no evidence of any serious defect in the metal supplied by these establishments, and it may be concluded that the inspection was thorough and creditable.

As a whole, the staff was inefficient and not well organized; the excellence of the work done must be largely attributed to the ambition of the constructors to do the work to the very best of their ability; the organization was weak in the absence of a fully competent engineer of erection, and of a forceful chief of staff for the inspection of shopwork.

The officials of the Phoenix Bridge Co. most closely connected with the Quebec bridge were the chief engineer, the designing engineer, the engineer in charge of details, the shop inspector, the superintendent of erection, the erection foreman, the resident engineer of surveys, and the resident engineer on erection.

The chief engineer was Mr. Deans, who has occupied this position for many years, and is widely and favorably known as an experienced bridge builder. Mr. Deans' personal duties are the general oversight of all work being executed by his company. He may be fairly described as its chief business manager, and as such conducted all the negotiations leading up to the Quebec bridge contracts. From the nature of his work it is not possible for him to be closely in touch with the planning and execution of technical details; these were in the direct charge of his two principal assistants, Mr. Szlapka and Mr. Milliken, acting under his general instructions. Mr. Deans was very active in the performance of his duties, kept closely in touch with the progress of the work in all departments and generally managed the execution of the contract.

Mr. Deans' actions in the month of August, 1907, and his judgment, as shown by the correspondence and evidence, were lacking in caution, and show a failure to appreciate emergencies that arose.

The designing engineer was Mr. Szlapka, who had received a thorough technical education in Germany and has been with the Phoenix Bridge Co. for about 27 years, having held his present position for 21 years. A list of the more important structures that have been built by this company to Mr. Szlapka's designs will be found on p. 935 of the evidence, and shows that previous to 1903 his ability as a designer had been thoroughly tried and that his experience was wide. As usual in present bridge company organizations, Mr. Szlapka's work has been confined to his own department, and his personal knowledge of the work of transportation and erection is limited. The evidence shows that Mr. Cooper, whose faculty of direct and unsparing criticism is well known, had every confidence in the ability of Mr. Szlapka, and on previous works had had good opportunity to form his estimate of him. Mr. Szlapka was responsible for the entire work of designing, and the commissioners are satisfied from their personal investigations at Phoenixville that this was conducted with care and energy. Mr. Szlapka's mistakes and errors, to which the disaster is directly attributed by the commissioners, are discussed elsewhere.

The engineer in charge of details was Mr. Charles Scheidl. Mr. Scheidl had received a technical education in Germany, and has been with the Phoenix Bridge Co. for 24 years, during 18 of which he has held his present position. His work in connection with the Quebec bridge is clearly and fully set forth in his testimony commencing on p. 914 of the evidence, and, briefly stated, consisted of preparing the shop drawings from the general outlines of design that had been determined by Mr. Szlapka. The accuracy with which this work was done is proved by the records of the shop, inspectors and of the erectors, and was of the highest grade. Upon Mr. Scheidl was laid the burden of being personally responsible for the accuracy of every one of the shop drawings.

Mr. E. T. Morris was shop inspector for the Phoenix Bridge Co., his position being a permanent one. His duties were similar to those of Messrs. Edwards and Meeser, and his employment practically provided for an additional inspection of the work in the shop. He reported to Mr. Deans and Mr. Szlapka, and kept a record of all errors detected and of the methods adopted for their correction. An examination of the "field corrections" reported by the resident engineer of erection will show how thoroughly this shop inspection was done, and by comparison of the records we find that the work of Mr. Morris was even more thorough and exact than that of Messrs. Edwards and Meeser. It is proper to credit the thoroughness with which this work was performed not solely to Mr. Morris, but also to Messrs. W. H. Reeves, Deans and Norris, whose emphatic instructions concerning inspection he had received.

Mr. A. B. Milliken was superintendent of erection, having general jurisdiction over the handling of all the contracts of the company after the material was delivered to it by the Phoenix Iron Co. He has occupied his present position for about 17 years. A list of the most important structures that he has erected is given in his evidence (pp. 52 and 53). Mr. Milliken did not confine his attention to the Quebec bridge work, but had the execution of several other contracts to look after at the same time. The evidence shows that he spent much time at the site, and was always closely in touch with the work. The system of reports of progress established in his department was very thorough.

Mr. Milliken reported to Mr. Deans, and when on the work did not interfere with the jurisdiction of Mr. Yenser, who was in charge, but simply advised him. His work throughout appears to have been thoroughly and carefully done. The system of erection was jointly designed by the engineering and erection departments of the Phoenix Bridge Co., the details of the members, their connections, the travelers, and the general order of erection being determined by the engineers, and the equipment of plant and tackle by the erection department. Mr. Milliken appointed Mr. Yenser as foreman on the Quebec bridge.

Mr. B. A. Yenser was Mr. Milliken's subordinate in charge of erection, and was in absolute local authority. He had been a bridge erector for many years, and had worked for the Phoenix Bridge Co. for about 15 years. In Mr. Deans' evidence will be found a statement of the more important structures erected by Mr. Yenser, and that gentleman is described as "having shown unusual qualities as an erector, being careful and conscientious, and having had experience in the handling of men." It should be noted that Mr. Yenser had absolutely no authority to vary the programme of erection, which was arranged in Phoenixville and furnished to him in a book of instructions with accompanying plans. His position was largely an executive one, his duties being to carry out positive instructions, and to see that the forces employed were worked to their full efficiency. He had orders to exercise extraordinary care in the inspection of the tackle and all handling appliances. Mr. Yenser had no technical training, and his position did not call for it. His action in continuing erection on Aug. 28, 1907, was immediately referred to his engineering superiors and was approved. The evidence shows that he was an able and forceful superintendent, and that he went to his death with supreme confidence in the judgment of his superiors at Phoenixville.

Mr. A. H. Birks, the resident engineer of erection, who also perished in the disaster, had complete confidence in the ability and efficiency of the Phoenix Bridge Co.'s designers, whose abilities he had had ample opportunity to observe. The personality of Mr. Birks is described and his record in the performance of his duties is stated in Mr. Deans' testimony on pp. 42 and 900. It will be there noted that Mr. Birks' experience was rather limited. He had received a thorough training in the design of the erection plant. His duties were to inspect the material as it arrived on the bridge for erection, to see that it was properly placed, and to watch the erectors to see that the programme of erection as laid down in the Phoenixville written instructions was minutely followed. The evidence shows that these duties were performed with intelligence and fidelity. Mr. Birks prepared all technical reports for transmission to Phoenixville, and advised Mr. Yenser on matters calling for engineering knowledge.

Mr. F. A. Cudworth was resident engineer in charge of surveys. No question of importance affecting Mr. Cudworth's work has come up in the progress of this enquiry and it is sufficient to say that his duties were faithfully and ably attended to. The Phoenixville office depended upon him principally for reports of the movements of the various parts of the truss as the erection proceeded, and his observations are matters of record.

In general, it may be said that this staff was highly efficient, the men were well trained and had ample experience in the class of work that they were called upon to do, and there is throughout evidence of great pride in their individual connection with the undertaking and of determination to do their utmost to make it a success in every way. The Commissioners are of opinion, however that the Phoenix Bridge Co. erred in judgment and showed a failure to appreciate the magnitude and difficulties of the work that it had undertaken when it did not provide as part of this organization an engineer of erection who, by virtue of technical training and long experience on large bridge work, was fitted to take complete local control of the erection. In this they followed usual practice, which, however, was not applicable to this particular work.

The manager for the Phoenix Iron Co. was Mr. Norris, who has been prominently connected with the company since 1896, and who became manager in 1900. Under his management the works of the company have been altered and enlarged and the output materially increased. Mr. Norris' endeavor to secure thoroughly good material and good workmanship for the Quebec bridge is set forth at length in his testimony, and his conduct of the work throughout is, in the opinion of the Commissioners, commendable for its carefulness, thoroughness and energy.

The Commissioners are of opinion that the works of the Phoenix Iron Co. are efficiently managed and operated.

(Signed) Henry Holgate,
Chairman.
J. G. G. Kerry.
J. Galbraith.

APPENDIX 8.—A HISTORY OF THE DEVELOPMENT OF THE PLANS AND OF THE METHODS FOLLOWED IN THE DESIGNING OFFICE.

The first preliminary plan of the Quebec bridge was made by the Phoenix Bridge Co. for the Quebec Bridge Company and is dated Nov. 30, 1897. A second plan was made Dec. 7, 1897, showing the lower chord curved. In response to our inquiry, Mr. Szlapka states that the change from the straight to the curved lower chord was made for the sake of artistic appearance, either form being considered by him structurally satisfactory.

There are three other plans, dated Feb. 17, 1899, two of which show the lower chord of the anchor-arm arched at both ends, and the other shows the anchor-arm arched only at the main pier. In general outline this last plan was almost identical with that of the final design.

All of these five general preliminary plans are drawn for a river span of 1,600 ft. The plan of Nov. 30, 1897, shows the cross-section of the river correctly, which indicates that information of this nature had been received from the Quebec Bridge Co. prior to that date.

The plan made by the Phoenix Bridge Co. and dated Dec. 7, 1897, is identical as to bridge outline with the plan dated Jan. 13, 1898, and filed in the Department of Railways and Canals by the Quebec Bridge Co.

The plan which accompanied the tender of March 31, 1899, was one of the three plans dated Feb. 17, 1899. This design and others of the same date, some of which were competitive designs, are shown on drawing No. 23.

Two more plans were made, dated April 22, 1900, both of which show the anchor-arm, with a lower chord in the shape of a complete arch, the main span on one being 1,723 ft. and on the other 1,800 ft. The contract for the bridge having been awarded on April 12, 1900, these plans were finished after the formal award was made; but the correspondence shows that the discussion of the lengthening of the mainspan had been going on for some time before April 12. Mr. Cooper's report recommending the 1,800-ft. span is dated May 1, 1900. Another general plan, showing a bridge with practically the same outline as that used for the final design, was completed on May 6, 1900, and this, with slight modifications, was used in making a plan dated Oct. 6, 1900, and having the name of the Quebec Bridge Co. in place of that of the Phoenix Bridge Co. in the title. On April 14, 1901, the last preliminary general plan was made. All these preliminary plans were made by the Phoenix Bridge Co.

On April 12, 1900, the contract embracing the anchorage steel work was signed. The plans for this work were developed in the regular course, and work was done accordingly. In this contract the Phoenix Bridge Co. was awarded the contract for the steel work of the whole structure and agreed to proceed with detail plans. On Dec. 19, 1900, the contract for the two approach spans was signed. The plans for this work were developed, and the work was finished in due course.

While the approach spans were simple truss spans of unusual design for such structures, and complete in themselves, the anchorages for the cantilever bridge involved calculations of the main structure, in order that the uplift could be determined. Such calculations as were necessary to ascertain this were made on assumed data. The work was ordered June 15, 1900, and forthwith designed and constructed, with "a liberal allowance for increase of uplift," as the exact uplift could not be ascertained, the weight of the structure itself not being then known and only approximately estimated.

A general study of the details of the bridge was made by Mr. Scheidl during the months of January, February and March, 1902. This study involved the consideration of the outlines of the bridge and of the general stress sheets which had been prepared. The method of connecting the suspended span to the cantilever-arms, the details of the shoes for the main posts and the details of the anchorages were considered; the detailing of the panel points and intersections of the suspended span was worked out; then followed the arrangement of the top chord packing for the cantilever and anchor-arms, the panel points and intersections, the main posts and pedestals, etc. These studies not being considered as other than tentative, the weights were not computed at that time as a basis for new stress sheets. The real preliminary work intended for final results was begun in July, 1903, after the receipt of the revised specifications, the contract having been signed provisionally on June 19.

The following is an outline of these preliminary studies. First, the determination of the normal lengths of all the bridge members; then studies of all plate and trussed floor beams and stringers; of transverse bracing, details of main shoes, pedestals, connecting chords and bracing of same.

The packing of the eye-bars was then taken up; then the details for anchorages and the transfer of wind stresses and anchor piers. Then followed the detail of the anchor-arm panel points, commencing with the end lower chords; then the web intersections. Similar studies were made for the cantilever-arms and the suspended span.

When the details for the anchor-arm were completed and those for the cantilever-arm partially completed the weights of all details were calculated and final anchor-arm stress sheets computed. This was the beginning of the shop drawing period; only the anchor towers had then been shop detailed.

The dead load concentrations upon which the final make-up of the members of the anchor-arm was based were as follows:

Half-suspended span..............	4,842,000 lb.
Cantilever-arm	13,205,200 "
Anchor-arm	13,317,600 "

The corresponding concentrations, as determined on June 25, 1907, were found to be:

Half-suspended span..............	5,694,000 lb.
Cantilever-arm	15,804,000 "
Anchor-arm	17,318,000 "

(See also drawing No. 3.) The total steel in the latter concentrations was about 35,316,000 lb.

The difference between these two sets of concentrations indicate a fundamental error in the calculations for the bridge. In a properly computed bridge the assumed dead load concentrations upon which the make-up of the members is based should agree closely with the weight computed from the dimensions in the finished design and with the actual weights. (See clause 3 of the specifications, which provides: "3. The dead weight used for calculating stresses must not be less than the actual weight of structure when completed.")

The error consists not so much in the assumed concentrations being incorrect, for that is more or less unavoidable, but in the fact that a recomputation of weights based upon the cross-sections already determined and with sufficient allowance for doubtful details was not made, and a process of approximation continued until satisfactory agreement was reached. In bridges of ordinary design and dimensions experience has furnished data sufficient to enable the designer to estimate the weight so accurately that a recomputation is not always necessary. In this case, however, the unique character of the design, the magnitude of the span and the high unit stresses specified demanded that no risks should be taken by failing to adopt this method of approximation and checking.

In computing the make-up of the members of the cantilever-arm the same dead load concentrations were assumed for the cantilever arm and for the suspended span as in the computations for the anchor-arm, and the above comment will apply with equal force to the design of the cantilever-arm.

The failure to make the necessary recomputations must be attributed mainly to the over-confidence of Mr. Szlapka in the correctness of his assumed dead load concentrations. Mr. Cooper shared this confidence since he approved the stress sheets.

The dates of approval of the various stress sheets by Mr. Cooper are as follows:

Suspended span..................	March 29, 1904
Anchor-arm	June 30, 1904
Cantilever-arm	May 25, 1905

Mr. Cooper's examination with regard to the question will be found on pages 1006, 1007, 1008 and 1009 of the evidence. On page 1009 Mr. Cooper says:

"In computing the dead load strains I was furnished by Mr. Szlapka with a diagram, dated May 12, 1904, which gave the dead load concentrations for the anchor and cantilever-arms, Quebec bridge.

"These dead load concentrations vary at every point. I asked Mr. Szlapka when this was presented to me whether it was carefully and properly estimated. He states that he had his best men to carefully estimate the weight at each point, and that this was a correct arrangement of the final weight, to the best of his belief. As I had no other means of determining these weights, the plans not being yet submitted to me, I assumed them to be correct and used them in determining my strains. I did, however, check these weights in the following manner: I added together all the concentrated loadings, deducted the allowance for floor and timber, which he states here especially, and found that the resultant weight was abundant to cover the assumed estimated weight of the structure."

Early in 1905 the drawings of the anchor-arm were practically complete, and it was possible to compute the weight of the anchor-arm within, say, 2 per cent. of the actual weight. There is no evidence to show that this was done by the Phoenix Bridge Co. or by Mr. Cooper. Had such a computation been made at that time, when but a small portion of the work had passed through the shop, and erection had not begun, the serious error of the assumed dead load would have been immediately detected.

Shop work began in July, 1904, and the record shows that at the end of December, 1904, eight panels of anchor-arm lower chords had been completed ready for shipment. The demands of the shop on the drawing office no doubt contributed to prevent a recomputation of the stress sheets and the early discovery of the error.

Mr. Cooper did not become aware of the error until he received Mr. Edwards' report on material of Feb. 1, 1906. At this time practically the anchor-arm tower and two panels of the cantilever-arm were in place. Realizing that there was no remedy, and believing that the increased stresses were still within the limit of safety, Mr. Cooper permitted the work to proceed. He estimated that the increase in unit stresses due to this error was from 7 to 10 per cent.

No progressive record of computed weights was made and kept in the designing offices for the purpose of checking the estimated concentrations used in the stress sheets, as will be seen from the following correspondence with Mr. Deans:

"Montreal, Jan. 25, 1908.

"Messrs. The Phoenix Bridge Co.,
"Phoenixville, Pa.

"Dear Sir:

"I have been requested to ascertain from you the process or system you used in the drawing office, whereby the weights were estimated and ascertained, and what record of estimated and actual weights of parts was kept in the drawing office. Was it your practice as soon as a drawing was completed, to make an estimate of the weight of that part, and was this work done systematically so as to be of service in checking the original calculations of the bridge, and were the weights estimated from the drawings of service to you in furnishing data for design? If you can give me a list of these actual weights, with the dates at which they were ascertained, either from the estimate made from the drawing or from actual weight, whichever was first, it would, I think, give the information desired.

"I would be obliged to you for an early reply,

"Yours truly,
(Signed) "Henry Holgate,"

"Phoenixville, Pa., Jan. 31, 1908.

"Henry Holgate, Esq.,
"Chairman, Royal Commission,
"Montreal, Canada.

"Dear Sir:

"Replying to your letter, Jan. 25.

"When the shop drawings of the heaviest and largest pieces were partially finished sketches were prepared showing their approximate weights and extreme dimensions. These sketches were sent to the transportation companies to secure routing and method of loading. No weights were figured of any pieces of ordinary dimensions, where no difficulty whatever was expected in loading. After the shop drawings of the most important members were finished and approved by the consulting engineer, then their weights were figured with care for comparison with the shipping weights. No other record was kept in the drawing room outside of these itemized weights on forging lists of the estimated and actual shipping weights.

"Our shipping invoices give the actual weights, marks and dates of shipment of all pieces in the bridge. We have no extra copy of these, but no doubt you could get the loan of Mr. Hoare's record.

"Yours truly,
(Signed) "Jno. Sterling Deans.
"Chief Engineer."

Before commencing the shop drawings a full understanding was arrived at between the drawing office and the erection department regarding the positions of field splices and other details which might affect the erection. The large traveler was designed after consultation between the two departments.

Before shop drawings could be made for the larger pieces arrangements had to be completed with the transportation companies. This involved the making of transportation drawings for the purpose of avoiding all difficulties which might arise during transportation with regard to rolling stock, curves and bridges.

The exact dimensions of the various members had to be determined so that under normal loading the normal configuration should obtain. This involved the computation of all the alterations of lengths and of position in members from the first position of the anchor-arm lower chords on the false works to the final configuration of the bridge when complete and sustaining its normal load.

The methods of erection were fully considered in planning the details of the shop drawings. All the work, including the preliminary detailing already described, was under the charge of one assistant engineer, Mr. Chas. Scheidl. Each shop drawing, when completed, was fully checked. Copies were then forwarded to the consulting engineer for approval. When approved, copies were returned to the Phoenix Bridge Co., which sent copies to the chief engineer of the Quebec Bridge Co., to be forwarded to the Department of Railways and Canals. The department returned one approved copy to the Phoenix Bridge Co., and in accordance with the terms of the contract, the receipt of the plans approved by the Department of Railways and Canals was the authority for the Phoenix Bridge Co. to construct the work.

All shop drawings were executed in the best style of draftsmanship and gave all necessary information for the shop and to some extent for the erection.

The most careful methods of checking were employed. At no time during the progress of the office work were more than eighteen men employed. The rate of progress depended upon the rate at which Mr. Scheidl could perform his work and would not have been hastened by the employment of a greater number of draftsmen.

The north and south halves of the bridge being identical, the members for each were constructed from the same drawings simultaneously.

The annexed table shows that the drawings were sent to the shops as soon as the approval of Mr. Cooper was obtained and that the approval of the Department of Railways and Canals, while necessary, was regarded as being purely formal.

The following is a condensed diary of the work more or less connected with the drawing office in connection with the structure as erected:

April 12, 1900—Contract for anchorages signed.

Dec. 19, 1900—Contract for two approach spans signed.

January, February and March, 1902—Tentative studies of details for main structure.

July, 1903—Preliminary studies for final design of main structure begun on receipt of the revised specifications. Contract signed provisionally on June 19.

July 23, 1903—Studies of floor system begun. Mr. Szlapka decides to arrange his work so as to complete the shop drawings for the anchor and cantilever-arms not later than Aug. 31, 1904, giving the shops eight months to complete 20,000,000 lb., so that erection might begin May 1, 1903.

January to May, 1904—Computation of stress sheets and make-up of anchor-arm.

March to December, 1904—Computation of stress sheets and make-up of cantilever-arm.

Feb. 19, 1904—General drawing and stress sheets of suspended span sent to Mr. Cooper.

March 21, 1904—Mr. Deans instructed Mr. Szlapka to push all work with the utmost dispatch.

March 29, 1904—Stress sheet of suspended span approved by Mr. Cooper.

April 8, 1904—Mr. Szlapka advises Mr. Hoare that weight of bridge would not be more than 5 per cent. above the estimate, or, say, 62,720,000 lb.

April, 1904—Large traveler designed and weight determined for computing erection stresses.

May, 1904—General detail drawing suspended span approved by Mr. Cooper.

May 3, 1904—Details of anchor bents approved by Mr. Cooper.

May 13, 1904—Mr. Szlapka sends Mr. Cooper dead load concentrations for cantilever and anchor-arm so that Mr. Cooper might check his stress sheets.

May 23, 1904—Preliminary study of shoes and pedestals sent to Mr. Cooper. Also complete calculations for anchor-arm. Also first shop drawing for anchor bent.

May, 1904—All typical drawings of top and bottom panel points approved by Mr. Cooper.

June 2, 1904—Complete stress sheet for anchor-arm taken to Mr. Cooper by Mr. Szlapka.

June 6, 1904—Revised plan of anchor eye-bars sent to Mr. Cooper.

June 30, 1904—Mr. Cooper approves anchor-arm stress sheet.

July, 1904—Plate floor beams and stringers approved by Mr. Cooper.

July 10, 1904—First lower chord plans approved by Mr. Cooper and work begun on them in shop.

July 11, 1904—Copies of anchor-arm stress sheet sent to Mr. Hoare for transmission to Department of Railways and Canals.

July 28, 1904—Top chords approved by Mr. Cooper. After this drawings completed and forwarded to Mr. Cooper in a continuous stream.

August, 1904—Shop drawings of two end panels approved by Mr. Cooper.

The following letter from Mr. Deans to Mr. Hoare describes the situation as at Oct. 8, 1904:

"Oct. 8, 1904.

"E. A. Hoare, Esq.,
"Chief Engineer, Quebec Bridge & Ry. Co.,
"Quebec, Canada.

"Dear Sir:

"We find we have not received from the government engineer the approval of any main chord sections. As explained to you some time ago, we have been working at great disadvantage to ourselves in being compelled to confine our office work to the anchor-arm, in order that everything might be done that it is possible to do, to be ready early next spring to start the erection of the anchor-arm. There was too much work to do in the time allotted after the financial arrangements were made and work ordered ahead. We have not therefore been able to complete our stress sheets for the cantilever-arm and for the suspended span, it being necessary to await the completion of all details, not only of the permanent structure, but also the details and rigging of the main traveler that we may know exactly the total weight coming at each panel point.

SHOWING DATES AT WHICH VARIOUS OPERATIONS ON LOWER CHORDS OF SOUTH ARM WERE PERFORMED.

Dwg. No.	Location.	Sent to Mr. Cooper for Approval.	Returnd by Mr. Cooper Approved.	Sent to Mr. E. A. Hoare.	Approved by Dept. Rys. and Canals.	Drawings Received in Shops.	Templates Completed.	Starting of Punching.	Finished Punching.	Completed Ready for Shipment.
1	End Panel.	July 6, '04	July 10	....	Oct. 21	July 22	Sept. 1	Aug. 5	Sept. 26	Oct. 1-19 Oct. 1-20
2	Second Panel	Aug. 16	Aug. 20	Aug. 29	Oct. 21	Aug. 25	Sept. 25	Sept. 19	Oct. 1	Oct. 1-27 Oct. 1-24
3	Third Panel.	Sept. 10	Sept. 14	Sept. 22	Nov. 1	Sept. 16	Oct. 5	Oct. 11	Oct. 22	Nov. 1-8 Nov. 1-3
4	Fourth Panel.	Sept. 10	Sept. 24	Sept. 28	Nov. 1	Sept. 26	Oct. 11	Oct. 20	Oct 28	Nov. 1-12 Nov. 1-14
5	Fifth Panel.	Sept. 16	Sept. 24	Oct. 8	Nov. 1	Sept. 29	Oct. 31	Nov. 2	Nov. 17	Nov. 1-25 Nov. 1-26
6	Sixth Panel.	Sept. 14	Sept. 24	Oct. 13	Nov. 1	Oct. 4	Nov. 1	Nov. 10	Nov. 17	Dec. 1-3 Dec. 1-6
7	Seventh Panel.	Oct. 7	Oct. 13	Oct. 21	Nov. 12	Oct. 17	Nov. 14	Nov. 21	Dec. 3	Dec. 1-13 Dec. 1-17
8	Eighth Panel.	Oct. 14	Oct. 18	Nov. 4	Nov. 23	Oct. 24	Nov. 18	Dec. 4	Dec. 17	Dec. 1-24 Dec. 1-31
9	Ninth Panel.	Oct. 19	Oct. 23	Nov. 4	Nov. 23	Oct. 28	Nov. 25	Dec. 13	Dec. 31	Jan. 1-12,'05 Jan. 1-16
10	Tenth Panel.	Oct. 21	Oct. 25	Nov. 23	Dec. 19	Nov. 7	Nov. 28	Dec. 28	Jan. 5,'05	Jan. 1-18 Jan 1-19
	Column	1	2	3	4	5	6	7	8	9

Compare Column 4 with 5
Compare Column 4 with 9

"We have, as you know, sent to the Canadian engineers, through your office, the stress sheets for the anchor-arm, covering the chords which have not been approved, and we would kindly ask that they be examined and prints sent to us, with their approval, as soon as possible. The engineers have everything that is necessary to check these chords, although we thoroughly appreciate they would like to have before them these stress sheets of the entire bridge, and these will be sent with the least possible delay.

"Yours truly,
(Signed) "Jno. Sterling Deans,
"Chief Engineer."

Nov. 19, 1904—Plan of center post approved.

January, 1905—Series of eye-bar tests made.

March 3, 1905—Drawings for main shoes sent to shops.

May 25, 1905—Mr. Cooper approves stress sheets for cantilever-arm.

July 12, 1905—First detail drawing cantilever-arm chord No. 9 sent to Mr. Cooper.

July 13, 1905—Stress sheet for cantilever-arm approved by Department of Railways and Canals. Anchor-arm at this stage nearly all fabricated. Mr. Szlapka expected to finish the shop drawings for first two panels of cantilever-arm by Sept. 1, and all the drawings for the bridge by March 15, 1907.

July 20, 1905—Mr. Cooper and Mr. Szlapka discuss the testing of riveted links and other matters. Use of slightly higher steel for eye-bars and some corrections in camber all satisfactorily agreed upon.

Aug. 11, 1905—First lower chord sections of anchor-arm erected in position and practically whole of anchor-arm fabricated, a large amount having been delivered at bridge site.

June 14, 1906—Development of drawings so far advanced that the Phoenix Bridge Co. made a closer estimate of the weight of the steel in the structure, which, including the anchorages, was placed at 73,500,000 lb. The weight finally was estimated at 73,312,504 lb. The actual weight averaged about 1 per cent. heavier than the weight computed from the drawings.

QUEBEC BRIDGE—SOUTH HALF.

Statement Showing Comparison of Actual Weights and Weights Figured from Completed Drawings.

Order No.	Description.	Figured weight, lb.	Actual weight, lb.
602.	Anchorage eye-bars and pins..	219,829	223,100
604.	Anchor shells and bracing....	374,697	371,843
	Anchorage	594,526	594,943
606.	Anchor-arm trusses..........	8,085,621	8,142,803
608.	Anchor-arm eye-bars..........	3,188,361	3,209,014
610.	Anchor-arm pins.............	229,058	229,255
	Anchor-arm truss system........	11,503,040	11,581,072
613.	Anchor-arm floor b. & str.....	1,507,140	1,517,036
618.	Anchor-arm trusses floor b....	260,832	261,510
	Anchor-arm floor system.........	1,767,972	1,778,546
612.	Center posts and bracing......	2,676,863	2,708,560
614.	Shoes and pedestals...........	808,810	814,349
	Center post system..............	3,485,673	3,522,909
621.	Cantilever-arm trusses........	8,602,086	8,724,598
623.	Cantilever-arm eye-bars.......	3,467,005	3,468,253
625.	Cantilever-arm pins..........	330,220	329,584
	Cantilever-arm truss system.....	12,399,311	12,522,435
627.	Cant.-arm floor b. and str.....	1,732,290	1,770,892
629.	Cant.-arm trussed floor b......	290,435	296,206
	Cant.-arm floor system..........	2,022,725	2,067,098
631.	Susp. span trusses............	3,307,590	3,379,293
633.	Suspended span eye-bars......	342,340	343,280
635.	Suspended span pins..........	35,710	35,460
	Suspended span truss system.....	3,685,640	3,758,033
637.	Susp. span floor b. and str....	1,197,365	1,214,905
	For one-half of the bridge.......	36,656,252	37,039,941
	The whole bridge.................	73,312,504	74,079,882
	Actual weight in excess of weight estimated from drawings		767,378

Percentage of errors, 1.03 per cent.

Actual weight is 101.05 per cent. of figured weight.

Figured weight is 98.95 per cent. of actual weight.

Sept. 25, 1907.

Nov. 26, 1906—The south anchor-arm, nearly all the south cantilever-arm erected.

Feb. 1, 1907—Stress sheets of the suspended span revised.

March 15, 1907—The last drawing completed, being that of the lower chord of center panel of suspended span.

June 25, 1907, to Oct. 8, 1907—Dead load concentrations for suspended span, cantilever-arm and anchor-arm revised and new cross-sectional areas for members of bridge computed for purposes of comparison with actual cross-sections.

(Signed) Henry Holgate,
Chairman;
J. G. G. Kerry,
J. Galbraith.

APPENDIX 9.—MATERIAL, SHOPWORK AND INSPECTION.

The steel supplied for the bridge was made to meet the requirements of the Hoare specifications with the exception that Mr. Cooper, finding that the tests on the full-sized eyebars were running a little low, called for the use of a slightly higher material for eyebar blanks.

The Hoare specifications called for an ordinary grade of structural steel very similar to the regular output of the mills. The testing requirements were not onerous, but were in accordance with current practice.

The behavior of the metal, as evidenced by the wreck, was so good that the Commission was convinced that the disaster could not be traced to the furnaces or rolling mills. Its examination of these was accordingly rather general in character.

The following amounts of metal were supplied by the different mills:

	Lbs.
Phoenix Iron Co., shapes....................	16,575,888
Central Iron & Steel Co., eyebars, blanks.....	14,827,400
Central Iron & Steel Co., plates............	27,240,100
Carnegie Steel Co., plates..................	13,822,000
Bethlehem Steel Co., pins...................	993,600

The Commission visited the works of the Phoenix Iron Co., of the Central Iron & Steel Co. and of the Pennsylvania Steel Co., the latter corporation having supplied a large tonnage of slabs to the rolling mills of the Central Iron & Steel Co.

On our inspections we were accompanied by the mill inspectors employed by the Quebec Bridge & Ry. Co. and the details of the manufacture of the steel, of the rolling of the shapes and plates and of the work of the inspection were explained fully to us both by these gentlemen and by the superintendents in charge of the various works.

We desire to acknowledge here the courtesies extended to us by Mr. J. B. Bailey, manager of the Central Iron & Steel Co., and by Mr. Reynders, vice-president of the Pennsylvania Steel Co.

The tests of material called for in the Hoare specifications were regularly made by the rolling mills under the supervision of the inspectors for the Quebec Bridge & Railway Co. An examination of these records, there being in the neighborhood of five thousand tests in all, shows that there was nothing abnormal about any of the material and that it satisfactorily met the requirements of the specifications.

Full-sized tests of some seventy eyebars were also made in the large machine at Phoenixville in accordance with the requirements of the specifications. The results of these tests are given in Exhibit No. 107, and it will be noted that a number of the bars tested did not quite come up to specifications. The results of these tests were referred to Mr. Cooper, who agreed to accept a certain number of weak bars, but raised the rolling mill specification so that there would be no further difficulty of this nature. These full-sized tests were made on finished eyebars, prepared in all respects as were the eyebars that were used in the bridge.

Mr. Cooper's statement that "the various members of this bridge will exceed anything heretofore made and will tax to the utmost the manufacturing appliances of the time" is a fair description of the work that the Phoenix Iron Co. had undertaken to perform.

When the Phoenix Bridge Co. provisionally signed the final contract of June 19, 1903, its sub-contractor, the Phoenix Iron Co., was not fully equipped for the carrying out of the work and additions and changes had to be made both to its buildings and to its plant.

The study that had been given to improvement of equipment preparatory to the acceptance of the Quebec contract is set forth in the evidence of Mr. Norris, and the Phoenix Iron Co. was ready to commence making the necessary changes as soon as the contract was accepted.

The total expenditure then made on improvements was over $220,000, divided as follows:

Enlargement and improvement of eyebar plant..	$40,000
Alterations of buildings and installation of overhead cranes sufficiently powerful to handle weights of 100 tons........................	110,000
New machinery, including a 64-in. double rotary planer for facing the compression chords, a plate straightener for large, thick plates, hydraulic shears for heavy sections, larger boring mills, large vertical planer and sundry alterations to other machinery..................	70,000

This expenditure was necessary before the Quebec work could be properly handled and is an evidence of careful preparation for that undertaking; the additions themselves constitute a permanent improvement to the iron company's plant and are now in constant use as part of its regular working equipment.

The evidence shows that Mr. Reeves and Mr. Norris fully appreciated the difficulty of manufacturing the large and complicated pieces of the Quebec bridge and that the various superintendents and foremen were warned to give more than usual attention to the execution of the work. As a preliminary a full-sized wooden model of one of the panel points of the lower chord of the anchor-arm was made and remained set up for the inspection of the shopmen. All details, such as the heads of rivets, etc., were shown on this model so that the shopmen could realize the mechanical accuracy that was necessary in order that the several members meeting at a point would go together in the field.

The Commissioners spent some days in the workshops with the iron company's foremen and with the inspectors for the Quebec Bridge & Ry. Co. in order to familiarize themselves with the work of fabrication and inspection. There was nothing peculiar to the Quebec work other than the great size and weight of the pieces to be handled, and the usual bridge shop methods were followed, the provisions of Mr. Cooper's standard specifications having to be observed for workmanship.

It was the obvious intention of the iron company to do a first-class piece of work, and it is in evidence that the management impressed not only on its own officials, but also upon the employees of the Quebec Bridge & Ry. Co. its desire that the shop inspection should be thorough and rigorous.

All pieces were inspected twice, once by the regular shop inspector employed by the Phoenix Bridge Co. and again by the inspectors for the Quebec Bridge & Ry. Co. In the more delicate work the inspectors had orders not only to test the finished pieces, but also to test the setting in the machines before the final cuts were made.

It was the practice of the shop to make the duplicate pieces for the north and south halves of the bridge at the same time, so that the bridge material now lying in Belair Yard was manufactured under exactly the same conditions as that which was erected from the south shore. The Commission spent some time examining the material in Belair Yard for the purpose of satisfying itself concerning the finish of the workmanship on the lower chords. This was found to be by no means perfect, but the errors measured were of small amount. The shops were defective in that they lacked a well founded floor for the assembling of the heavy pieces. The methods adopted were also defective in that adjoining compression members were not fitted together before shipment. Some of the minor, but by no means neglible, errors discovered in Belair Yard would have been detected by this fitting and it is a customary practice on heavy work. That errors similar to those observed at Belair existed on the south half of the bridge there can be no doubt and Mr. Kinloch states that such errors were observed by him. That these minor errors at the joints contributed in some degree to the final disaster is probable, but our criticism in this case is not of the shopwork, which was of a fair grade. The fault lies in a design which called for an accuracy beyond the working limits of good shop practice.

The errors now being discussed are differences of length of the several ribs making up one chord and irregularities of surface at the field joints of the lower chords. The chord faces are found to be slightly dished and not true. It is not possible to determine by analysis the result of these slight errors, the larger of which would not exceed 3/64 in. in dimensions.

The inspectors were instructed to work to the nearest 1/64 in., but such accuracy is hardly practicable. We do not consider that such high accuracy can be maintained, at least not without fitting together adjoining pieces in the shop.

It is probable that some portion of the errors noted at Belair was due to the unavoidable racking of the members while in transport.

Both sets of inspectors worked with steel tapes that had been carefully compared and kept books of record stating the errors discovered in their inspections and the methods adopted in correcting them. In cases of difficulty the question was referred to Mr. Szlapka for instructions and occasionally to Mr. Cooper.

Some few errors escaped detection until the work was being erected in the field; the drafting room and not the machine shop was responsible for several of these. None of these final errors were of a serious nature and the necessary corrections were made without difficulty.

Mr. Edwards has recorded the following number of errors:

In the Anchor-Arms: 23 in the stringers, 2 in the floorbeams, 17 in the lower chords, 20 in the main posts, 7 in the hangers, 4 in the eyebars, 6 in the pedestals and shoes, 1 in the main diagonals, 14 in the laterals, 15 in the struts, 2 in the pins, 8 in the plates and in knee braces, giving in all 119 errors.

In the Cantilever-Arms and Suspended Span: 27 in the lower chords, 10 in the floorbeams, 8 in the stringers, 8 in the diagonals, 4 in the struts, 4 in the hangers, 34 in the main posts, 4 in the laterals, 5 in the eyebars, giving in all 104 errors.

As the inspection requirements were more severe than is customary on ordinary bridge work and as the shopmen had never been called upon to handle work of such magnitude before, it was natural that a number of errors should be made and that this number should decrease proportionately as the conditions of the work became better known to the men.

It will be noted from the figures given above that such a decrease in the number of shop errors did take place, and in the correspondence the better quality of the workmanship on the cantilever-arms, when compared with that on the anchor-arms, is referred to from time to time.

Mr. Kinloch states in his evidence that in spite of the magnitude and difficulty of the work which would reasonably account for an unusual number of shop errors, the number actually found during erection was not in excess of what would be regularly expected on much simpler work.

Mr. Edwards' list of errors, which is not so ample as that prepared by Mr. Morris, looks, in a statement, to be rather serious, but when the number and magnitude of the pieces are remembered it cannot be considered to indicate carelessness or insufficiency in the shops. Some errors will always occur.

On the whole we consider that the inspection of the material and the work both in the mills and shops was reasonably efficient and that the collapse of the bridge is not attributable to want of care in either.

Some special shop work errors that occasioned a good deal of correspondence are referred to elsewhere.

The evidence shows that Mr. Cooper was seriously annoyed at the number of shop errors reported and reprimanded the inspectors very sharply, but the ease with which the structure was erected indicates that their work was fairly well done.

The lines of the several ribs in the chords are known to have been wavy to the extent of from ½ in. to ¾ in. (Evidence p. 504), but errors of this size and kind do not appear to have been considered a cause of anxiety. The existence of these wavy bends had been noticed by the shop inspectors and had been reported both to Mr. Szlapka and to Mr. Cooper.

We find no evidence to show that the seriousness of such minor errors in the compression chords and posts was appreciated by the engineers or was ever impressed by them upon the inspectors.

(Signed) Henry Holgate,
Chairman.
J. G. G. Kerry.
J. Galbraith.

APPENDIX 10.—TRANSPORTATION AND ERECTION.

In the practice of steel bridge design details are of vital importance and connections which may appear to be simple and satisfactory frequently prove to be impossible of execution. The complete study of the details therefore involves patient and skilful work and necessarily occupies a great deal of time.

A large portion of the time spent on the Quebec bridge plans by the designers was devoted to the study of practical details.

Four main principles had to be preserved:

(1) The site of the metal shapes and plates called for in the bills of material had to be limited to the dimensions that the rolling mills could furnish. It will be noted by reference to Appendix No. 9 that a large tonnage of metal was made for this bridge by the Carnegie Steel Co., neither the Phoenix Iron Co. nor the Central Iron & Steel Co. being able to make the larger plates.

(2) The members had to be designed so that the machines in the shop could make them. It will be noted by reference to Appendix No. 9 that the Phoenix Iron Co. had to provide a number of new machines with which to manufacture the Quebec bridge. These machines were not novel in design; they were simply larger than those previously used by the Phoenix Iron Co. and were required on account of the greater size of the parts entering into the work.

(3) The members had to be designed of such size and weight that the railways could transport them. To insure this it was necessary to know and comply with the clearances and weight limits of several different railroads. For some of the members special cars were provided so equipped as to make safe transportation a reasonable certainty. It may be noted that one member of the north half of the bridge has been lying in the Phoenixville yard for about three years awaiting the

renewal of certain railroad bridges over which it would have to pass to reach Belair Yard.

(4) The members had to be designed so that they could be easily and quickly erected to place with the appliances provided. This made it necessary for the designers to thoroughly study the system and appliances for erection. The erection equipment provided was almost entirely new, and much of it was built specially for this bridge.

The capacity of the erection equipment was sufficient, although demands made upon it were very great. Some of the members handled weighed 100 tons and one lift of two panels of eyebars was 145 tons. This was lifted and placed in position in the upper chord of the bridge without difficulty, proving the capacity and perfection of the apparatus used in erection.

It should be said that the errors and mistakes of the Phoenix Bridge Co. in connection with the bridge were made in the design, and that its work in detailing, shopwork and erection was excellent. The care and forethought given to the execution of the work cannot be better described than it is in the evidence of Messrs. Deans and Scheidl. We therefore add only a few explanatory remarks to those statements.

The bridge members were loaded on cars by the Phoenix Iron Co. and were shipped either to the Chaudiere or to the Belair storage yards. The facilities for loading, unloading and transporting the material were entirely satisfactory so far as the safe delivery of the members was concerned.

But four cases of accidents during transportation from the shop to the bridge are reported.

Mr. Milliken has given the particulars of an injury to one of the steel shells that stood on the anchor pier. This injury was due to an accident on the railway and was not important.

The accident to chord 8L anchor-arm which occurred in the Chaudiere storage yard and which is frequently referred to in the evidence, is discussed in Appendix No. 11.

An accident to center post 6R which occurred in the Chaudiere yard, is also referred to in Appendix No. 11. An injury occurred to one of the north side lower chords, which fell in the Phoenix Iron Co.'s yard, striking a center post cap. These pieces were repaired before they were shipped and have not yet been erected.

The work was delayed owing to lack of railway connections to the bridge site. The Quebec Bridge & Ry. Co.'s railway line, giving connection with the Chaudiere storage yard, was not opened for traffic until July 9, 1905, the first metal for the main spans being placed on the south anchor pier on July 22, 1905. Owing to lack of this connection all the metal for the anchorages and approach spans and all the material for the falseworks and traveler had to be sent to Levis or Quebec and taken to the bridge site on barges. The beginning of the erection of the main spans was delayed and considerable difficulty was experienced by the contractor owing to the congestion of the yards at Phoenixville and Belair. At the present date there are no railway connections with the bridge on the south side of the river; similar conditions existed on the south shore of the river early in 1905.

Great attention was given to the design and equipment of the erection traveler and it performed its work in a manner entirely satisfactory to the erectors. In evidence the erection workmen stated that they had never worked on a bridge on which better appliances were provided, or on which the erection programme had been more perfectly arranged. In order to hasten the erection of the bridge, which had been delayed by lack of rail connections, it was decided in January, 1906, to erect the suspended span with a small traveler so that the big traveler might be removed to the north shore at an earlier date. This programme, which was followed, was found quite satisfactory and it tended to increase the safety of the structure during erection, as erection stresses were thereby reduced.

At the time of the collapse of the bridge the small traveler was doing all the work of erection and the big traveler was being dismantled.

In the design of the bridge a normal configuration and loading was assumed in which the stresses in all the members were intended to be axial. In other words, under these conditions no bending stresses would exist at the various joints; under any other loading, therefore, angular changes would either take place or tend to take place at the joints; that is to say, bending stresses would exist.

The shop lengths of all members being computed so that in the normal configuration the members had the normal lengths, it resulted that during erection, when the members were under little or no stress, the whole configuration was distorted, as compared with the normal configuration. The falseworks upon which the anchor-arm was built had therefore to be arranged to conform to the initial configuration. After the anchor-arm was erected the building of the cantilever-arm gradually introduced and increased the stresses in the various members of the anchor-arm, and at a certain stage the anchor-arm became free from the camber blocks on the falsework, which were lowered to assist this movement.

In the original distorted form all field butt joints were in contact only at one edge, since in the normal form they would be in full contact. With the increasing loads on the cantilever-arm, due to the progress of erection, these joints gradually approached the condition of full contact and in doing so revolved about the edges in contact; in the meantime the splices were secured by bolts which could be changed, as the movement at the joints improved the matching of the holes. The instructions issued by the Phoenix Bridge Co. were that when the joints finally closed the splices should be permanently rivetted.

It must be apparent that during the movement in question the stresses at these joints were applied first only at the edges in contact, and that it was not until the joints were fully closed that there was any possibility of uniform distribution of stress. Indeed, this condition was not possible until the bridge would be completed and carrying its normal load, and the attainment of this condition would even then be dependent on the accuracy of the mechanical work at the joints.

The camber movements were regularly and carefully observed by the Phoenix Bridge Co.'s engineer in charge of survey work, and Mr. Deans states that these observations agreed closely with the expected movements as calculated by the designing engineers.

The adopted scheme of erection was carefully worked out in all details before the work of erection began. The results of this study were embodied in a book of field instructions, copies of which were furnished to the principal foremen on the work and to the representatives of the Quebec Bridge Co. These instructions were imperative and were not departed from or varied without approval of the Phoenix Bridge Co. at Phoenixville.

Mr. Kinloch, in his evidence, referring to these instructions, said: "In fact, you had only to follow instructions and the thing would get there itself if you followed the lines laid down." This statement coming from a bridge erector of Mr. Kinloch's experience is a tribute to the completeness of the prearranged system of erection.

There can be no doubt that the camber problem in the Quebec bridge was much more difficult than in ordinary structures on account of the magnitude of the bridge and the great size of its members.

The actual work of erection of the bridge began July 22, 1905, and continued for that season until Nov. 24. This work comprised six panels of the south anchor-arm.

In 1906 erection was commenced April 16 and continued until Nov. 29. At the end of this season's work the condition of all joints, as reported by Mr. Birks and Mr. Yenser, complied with the requirements of the Phoenix Bridge Co.'s instructions to their employees. At this date the anchor-arm and practically all of the cantilever-arm were erected.

Work of erection was resumed May 1, 1907, and continued until Aug. 29, the date of the collapse of the structure. At that date the fourth panel of the suspended span was in course of erection.

HENRY HOLGATE, Chairman.
J. G. G. KERRY,
J. .GALBRAITH.

APPENDIX 11.—A DISCUSSION OF THE DIFFICULTIES THAT AROSE DURING ERECTION AND OF THE EVENTS AT THE TIME OF THE COLLAPSE OF THE STRUCTURE.

The contract for the construction of the main spans was made conditionally on June 19, 1903, and finally accepted by the Phoenix Bridge Co. on March 15, 1904. By the first of August, 1904, the assembling of materials for the falseworks on the south shore had commenced, and by the beginning of September, 1904, the erection of the falsework was well under way. The wooden falsework for the supply tracks, and the steel falsework for the traveler and bridge trusses were erected simultaneously, not quite one-half of the falsework being put up before Dec. 1, 1904. The erection of the big traveler was commenced, and the storage yard at Chaudiere was in working order before the end of the season of 1904.

Season of 1905.—A considerable amount of material was delivered at the Chaudiere yard during the winter, but the work was not pushed in the spring of 1905 because there was no rail connection between the bridge site and the Chaudiere yard. This connection was completed on July 9, 1905, at which time the framework of the big traveler was being completed, and the falsework had been erected to the main pier, but not finished.

The equipment of the traveler was installed and the erection of the steelwork was commenced at the anchor pier on July 22, 1905. By the middle of September, the lower chords of the anchor arm had been erected, the pedestals and feet of the center posts were being placed and the erection of the web members and upper chords had commenced. By the end of the season, six panels of the anchor arm, out of a total of ten, were in place. The weight of metal erected during each month is given in the monthly estimate of the chief engineer, the total amount erected during 1905 being about 10,500,000 lb.

The work during the season proceeded satisfactorily both to the Phoenix Bridge Co. and the Quebec Bridge Co. There were some difficulties, which are described in the evidence. The more important of these were as follows:

FIELD CORRECTIONS, 1905.—The "field" filed notices of 21 corrections and alterations with the "office" of the Phoenix Bridge Co.'s erection department. These files up to Aug. 29, 1907, all concern minor alterations that would facilitate erection, but do not call for comment.

CHORD A 9-L.—In April, 1905, this chord had a severe fall while being handled in the Chaudiere yard. One of the hooks that were being used in raising it broke, and the whole chord fell, one end striking on a yard plate lying on the ground, and the other on a pile of eyebars. The drop was 5 ft. at one end and about 3 ft. at the other. The chord struck in such a way that any resulting bend would have been at right angles to the deflections measured on Aug. 27, 1907. Two lower flange angles were broken. This chord was repaired in July, 1905, in accordance with drawings received from Phoenixville, and to the satisfaction of the Quebec Bridge Co. We have examined these repairs since the fall of the bridge, and we find nothing to justify us in connecting them with the disaster. Whether the chord was strained by its fall so that it afterwards bent more readily under stress is a matter of conjecture that cannot be settled. A discussion of the failure of chord A 9-L under less than its working load will be found in Appendix No. 16.

PAINTING.—There was some discussion because the designs were such that water and snow could lodge in many pockets of the steelwork, and that other parts of it were inaccessible for future painting. Mr. Hoare considered that this was an "oversight" on the part of both the Phoenix Bridge Co. and Mr. Cooper, and on Mr. Kinloch's advice insisted on its being remedied. No changes were made, but better provision for painting was arranged for in the members not yet built.

MASONRY.—It was found necessary to delay the placing of the pedestals until the surface of the masonry upon which they were to rest was dressed level. Mr. Cooper would not permit the use of a lead plate under the pedestal, and had pieces of duck, heavily coated with red lead, used instead.

MAIN SHOE RIGHT TRUSS.—On placing this in position it was found that the bottom did not bear evenly on the pedestals, there being an opening parallel to the bridge center line about 4 ft. wide and perhaps 3/16 in. high at the maximum. It was decided that this would close as the weight on the shoe increased, but this closing had only partially occurred up to Aug. 29, 1907. The shop inspector (Mr. McLure in this case) states that no warp existed in the finished pieces in the shop, and that it must have been caused by handling and transportation. The matter does not call for further comment.

LOWER CHORD BENDS.—It was noticed by Mr. Kinloch that lower chords A 1-R, A 2-R, A 3-R, after they were set, and before any stress came on them, did not look straight, but were wavy to the extent of perhaps ½ in. He discussed this matter with Messrs. Birks and McLure and it was decided that it was of no importance. It was also noted early in September, 1905, that the openings at the lower chord splices did not correspond exactly with the erection diagram (Exhibit 60), "but seemed to average up about the same," and also that the inside ribs of chords at splices 1 and 2 did not line up well.

Season of 1906.—In 1906, erection commenced on April 16, and the south anchor-arm was all in place, with the exception of some decorative details, by June 27. Erection continued on south cantilever-arm and this was completed, with the exception of some connecting pieces between it and the suspended span, before work was closed down for the year, on Nov. 26. The total weight of metal erected during this season was about 21,000,000 lb. Work on the north shore commenced about the middle of July, and a small portion of the falsework was in position by the end of the season.

During this season few difficulties occurred, and these were of a kind usually met with in all large work. The following quotation from Mr. McLure's report to Mr. Cooper, under date of July 21, 1906, gives a fair idea of the conditions existing on the work: "The whole policy of the Phoenix erection department seems to be to make things safe and take no chances, which is a very satisfactory one to us, and in pursuance or this, everything is being bolted up in full in cantilever-arm, with the largest size bolts the holes will take, post and chord splices, main and sub-diagonal splices as well as all lateral and transverse bracing connections."

Field Corrections, 1906.—Fifty corrections and alterations were reported by the "field" during this season, none of them being of a serious character, so far as the safety of the bridge is concerned.

Painting.—The field inspector for the Quebec Bridge & Ry. Co. recorded many minor defects both in the arrangements for future painting and with regard to the shop painting that had been done. There are few bridges built upon which this difficulty does not arise.

Center Post.—Section No. 6 of this post in the Quebec truss (C P, 6-R) was injured while being handled in the Chaudière yard in April, the outstanding leg of one of the flange angles of an inner rib being broken through the slipping of a hoisting chain. This break was repaired during the summer in accordance with plans drawn by the Phoenix Bridge Co. and to the satisfaction of the Quebec Bridge Co.'s inspectors. There is no evidence to show that this break was a cause of the collapse of the bridge. On June 2, Mr. McLure reported to Mr. Cooper that the bearing surfaces at the top of C P, 1, both R and L, were not even and would not give a good bearing to the center post caps, these surfaces being made up of the tops of the posts themselves and of two brackets attached to each. Mr. Cooper immediately wired Mr. Hoare as follows: "Do not allow posts C P, 1 erected until top is made level. Notify McLure." Mr. Hoare immediately issued instructions to this effect. The Phoenix Bridge Co. sent Mr. Scheidl to check Mr. McLure's measurements, and the defect was finally made good in accordance with Mr. Cooper's detail instructions to Mr. McLure. The fault lay in the fitting of the brackets and in facing of the posts by the planer. Mr. Cooper considered such workmanship to be disgraceful, but the defects, as stated to him, were rather exaggerated owing to the methods of the measurement adopted by the inspectors.

Compression Members.—On July 20, Mr. McLure wrote to Mr. Edwards as follows: "On a number of the compression members that we have erected—particularly on three or four anchor-arm bottom chord sections, in chord 621 8L (south cantilever-arm, bottom chord) and in main diagonal sections for both anchor and cantilever arms (T5 and T50) and on 621 S P-5 sections (south cantilever-arm sub-posts) especially the latter—in sighting from end to end, the webs in places are decidedly crooked, and show up in wavy lines apparently held that way by the lacing angles. This makes a very bad appearance, for a person seeing a member like that and knowing it to be in compression, would at once infer that it had been over-strained sufficiently to bulge the webs. As to its actual effect in the number of cases I have figured out there is no possibility of these causing trouble, as long as the lacing in the members in question is intact." On Sept. 22, Mr. McLure reported to Mr. Cooper a deflection of ½ in. in a distance of 36 ft, and of ¼ in. in a distance of 17 ft. in the upper section of post 3-L, cantilever-arm (621 U P 3-L). Mr. Cooper replied that he did not like the distortions, but did not see that anything could be done at that stage. No effort was made to correct any of these irregularities, all of which were due either to shop errors or to racking in transportation. We do not connect these undoubted faults immediately with the disaster.

Removal of Steel Falsework.—In August, 1906, the Phoenix Bridge Co. issued instructions covering the removal of the steel falsework bents under members T. O. and P. I. anchor-arm. The draft of the instructions showed that the Phoenix Bridge Co. expected the portions of the anchor-arm near the main pier to lift first, as the weight erected on the cantilever-arm increased, but desired, for convenience of erection on the north shore, to take down the bents near the anchor pier as soon as possible. On Sept. 15 Mr. McLure reported these instructions in detail to Mr. Cooper and asked him for directions concerning the matter; he also reported that no lifting was yet visible at any point in the anchor-arm. On Sept. 17 Mr. Cooper directed Mr. McLure to permit the removal of the falsework, provided he was satisfied that the remaining bents would not be overloaded. On Sept. 29 Mr. McLure reported that E. P. R. had lifted clear of the falsework and on the same day it was noticed that T O O O-R was free. After discussion in the "field," the blocking under T 5-Z, both R and L was lowered ⅝ in., T 5 Z-R then swinging free. On Oct. 2 Mr. Cooper advised Mr. McLure that he thought the intermediate bents were too high and that he should examine them for evidences of extra loading and have them slacked down. "The whole must be rather a matter of careful observation and judgment rather than any reference to theoretical lines." Mr. Cooper read this letter to Mr. Szlapka and during the following week the blocking under T 5 Z, P-4 and T O O O O was lowered on orders from Phoenixville. As this was done without notice to Mr. McLure, who had received Mr. Cooper's instructions about the falsework, he immediately protested against this failure to recognize the inspectors of the Quebec Bridge Co. A short and rather sharp controversy arose over this, which was closed on Oct. 20 by a personal letter from Mr. Hoare to Mr. Deans, before quoted, in which Mr. Hoare very definitely asserts the importance of Mr. McLure's position as a representative of Mr. Cooper and himself and makes it clear that no important steps are to be taken in the future without Mr. McLure's knowledge:

"Quebec, Oct. 20, 1906.

"The Commissioners of the Trans-Continental Ry.

"Dear Deans: I wish to send you a few personal lines on the following matter. Mr. McLure showed me a letter dated Oct. 5 written by him to Mr. Milliken respecting the relieving of steel falsework bents under anchor-arm without giving him notice of such a procedure in order that Mr. Cooper first and then myself be previously notified. Mr. McLure has specific instructions to notify Mr. Cooper of any important procedure and receive in return any instructions that may be necessary. I fancy changes were made from Phoenixville to relieve the falsework. Mr. McLure, representing the bridge company's officers not daily on the work, should have been immediately informed notwithstanding the fact that you considered your instructions perfectly correct and safe. If Mr. McLure had been informed in time he could have wired Mr. Cooper your intentions without any delay to the work. I entirely indorse his letter to Mr. Milliken and to you on the subject of yours of the 8th inst. to Mr. Milliken.

"Both you and Mr. Milliken appear to have misunderstood Mr. McLure's letter. He did not for a moment intend interference with erection orders from your office, but makes a plain request to be informed of important moves of the above nature, and not be ignored, in order that he may perform his duty and carry out his instructions. I regret your remarks on his lack of experience, as it was uncalled for and is a reflection on the bridge company's supervision, and instead of helping matters the tendency will be to ignore general inspection orders which can be considered as given by me personally. Mr. McLure communicates daily with me and weekly with Mr. Cooper to receive instructions when necessary. I am writing you a personal and friendly letter which I hope will receive your usual generous consideration by seeing that Mr. McLure is better informed in future by your chief representative on the work of any proceedings of importance or of the nature referred to. Yours truly,

(Signed) "E. A. Hoare."

In the week ending Oct. 29 T 5 Z, P 4, T O O and E P were reported as free from the falsework and in the following week the blocking at T O O P 2, T O O O and P 3 was lowered, P 1 swinging clear while this was being done. By Nov. 3 only T O O and P 2 were still bearing and, by further lowering of the blocking, the whole truss was set free before Nov. 28. This record shows clearly that the right truss rose more quickly than the left truss and that the center of the anchor-arm remained resting upon the falsework for the longest time. In his evidence Mr. Cooper has expressed the opinion that the blocking near the center was left too high and that it acted as a fulcrum, permitting E P and T O to lift from the falsework at an early date, whereas, theoretically, they should have been the last to lift. He suggests that this condition may have produced an undue and unprovided-for strain on the anchor-arm splices. There is no evidence that any serious action of this nature took place, Mr. McLure having been unable to observe any signs of stress at the suspected points, and no deformations in a vertical plane being anywhere on record. In our opinion the failure of the Phoenix Bridge Co. to more closely adjust the blocking of the truss to its movements was an error of judgment, as the stresses produced by the gradual working of the truss are not calculable and the movement should be made as free as possible.

The Commission has been unable to satisfactorily determine the respective duties of Mr. Hoare and Mr. Cooper, their real positions being perhaps better brought out by the events of 1906 than by any other evidence. According to Mr. Deans Mr. Cooper had to approve all plans, but all other authority was vested in Mr. Hoare, and this opinion Mr. Deans continued to hold throughout the work. According to Mr. Parent Mr. Hoare was practically an executive officer acting in all technical matters on the direction of Mr. Cooper, who was, de facto, chief engineer. Mr. Cooper himself has stated that the erection plans were not subject to his authority and has disclaimed any responsible connection with the inspection either in the shop or in the field. With few exceptions, all his directions are advisory and not imperative, and he seems to have endeavored throughout to avoid encroaching upon the privileges and rights properly pertaining to Mr. Hoare's position. He gave frequent directions to both Mr. McLure and Mr. Edwards on technical matters, but throughout the construction period (August, 1905, to August, 1907) he had practically no correspondence with Mr. Hoare. Mr. Cooper's opinions, when given, were accepted by the inspectors as instructions. The impression left with us is that throughout the work Mr. Cooper was in the position of a man forced in the interests of the work to take responsibility which did not fully belong to his position, and which he was not authorized to take, and that he avoided the assumption of authority whenever possible.

Such an organization cannot from an executive standpoint be considered entirely satisfactory. Mr. Yenser closed the season of 1906 with the following report:

"New Liverpool, P. Q., Nov. 30, 1906.

"The Phoenix Bridge Co.,
"Phoenixville, Pa.

"Gentlemen:

"SOUTH SIDE.

"I beg to report to-day that all the bolting is fully completed on all metal erected in accordance with your instructions.

"The work for closing down for the winter is nearing completion. The traveler has been unrigged and all tools are properly stored. The engines on the traveler are housed and the shelters are now being covered with tar paper.

"The storage yard is closed and the locomotive put away.

"The large scow has been beached and preparations for putting the small scow in winter quarters are underway.

"A general report will be sent you at the entire closing for the season. Yours truly,

(Signed) "B. A. Yenser."

Season of 1907.—Work for the season of 1907 began in March, it being necessary to have a yard prepared to receive material on the north shore by early spring. The yard was located at Belair, close to the junction of the Canadian Pacific and National Transcontinental Rys. Work on the trusses began on May 1, but until May 31 was confined mainly to riveting. Using the big traveler, the connecting links between the cantilever-arm and the suspended arm were put in, and the smaller traveler was built. On July 13 the erection of the suspended span was commenced, the small traveler being used, and the dismantling and removal of the big traveler was begun. Both of these operations were in progress when the bridge fell on Thursday, Aug. 29.

On the north shore work continued at a leisurely rate from about May 15 until the day of the accident. The north shore falsework was not fully erected by that date, there being no reason to hurry, because rail connection could not be obtained.

During this season less than 3,000,000 lb. of metal was erected. The last progress estimate (August, 1907) showed that about 34,400,000 lb. in all had been erected.

Riveting.—It had been intended to delay much of the riveting of the structure until the erection of the south half of the bridge was completed and all joints had their full stress; but at a meeting between Mr. Cooper and Mr. Szlapka, on May 10, it was decided that riveting could be done at once at all joints where the connecting pieces had taken their full bearing. The estimate of the amount of field riveting in the south half of the bridge was as follows:

Part of bridge.	No. of rivets.
Anchor-arm and center posts	121,000
Cantilever-arm	98,700
South half of suspended span	53,300
Total	273,000

Some minor riveting was done in 1905, and in 1906 the joints of the floor beams and those near the anchor pier were riveted, but the bulk of the riveting was not started until 1907. Drawing No. 7 shows the dates on which the joints of the main trusses were riveted. The following table shows the number of rivets driven during the periods specified:

Period.	No. of rivets driven.
During 1905	7,807
" 1906	46,301
" May, 1907	31,517
" June, 1907	26,512
" July, 1907	38,917
" August, 1907 (not including Aug. 29)	28,019
Total	179,073

On Aug. 3 Mr. McLure reported that the anchor-arm was 90 per cent. riveted, although the bottom lateral braces in panels 6, 9 and 10 were not riveted; and that 40 per cent. of the riveting on the cantilever-arm was done. At the same date the lower chord splices at 5-6, 9-10 and 10-11 were the only chord splices in the anchor-arm remaining unriveted. Throughout the season the work proceeded satisfactorily; there were practically no difficulties until after Aug. 1.

Fourteen corrections and alterations were reported by the "field" to the office of the erection department. The surveys in May show that the truss had stood up very well throughout the winter, the movement of the center posts being trifling, indicating that the stresses then existing were well within the strength of the members. On July 20 a wooden derrick that was being used in the dismantling of the big traveler was struck by lightning. The derrick mast was shattered, but no other damage was done.

The difficulties with the lower chords that finally resulted in the collapse of the bridge were noted early in the season, but those first observed were considered to be of no minor importance. The joints between lower chords 5 and 6, anchor-arm, remained open 1/16 in. on the lower side, long after the others had closed. They finally closed shortly before the disaster, and on Aug. 29 were being riveted. No explanation has been offered of the slow closing of these joints, and from their nearness to the falsework bents at T O O and P 2 it is possible that the pressure of the falsework may have had something to do with this.

On June 15 Mr. McLure reported to Mr. Cooper as follows: "In riveting the bottom chord splices of south anchor-arm we have had some trouble on account of the faced ends of the two middle ribs not matching, as per following sketch. (The sketch shows that at the lower sides the middle ribs of the abutting chords were out of line by ⅛ to ¼ in., this offset decreasing to nothing near the mid depth of the ribs.) This has occurred in four instances so far, and by using two 75-ton jacks we have been able to partly straighten out these splices, but not altogether. These were probably in this condition when erected, but, owing to the presence of the bottom cover plate, it was then impossible to detect them, and it was only when this plate was removed for riveting that the inequality was noticed. The chords found in this shape were between 3 and 4, 7 and 8, and 8 and 9 in east truss, and 8 and 9 in west truss. You will note that this occurs only on inside ribs, which are provided with but a single thin splice plate each. I think that a heavy plate on each side of these ribs, bolted up tight when chords were erected, would have remedied this—*i. e.*, drawn the ribs together till the 'faced ends matched.'" Mr. Cooper replied on June 17, saying: "Make as good work of it as you can. It is not serious. It would be well to draw attention to as much care as possible in future work to get the best results in matching all the members before the full strains are brought upon them."

It should be noted that of the four joints mentioned, those between chords 3 and 4, and 7 and 8 had originally been opened at the lower side and had come together by "camber" movement; but the 8 and 9 joints had been set with the lower edges abutting. During the first stages of erection the upper edges of all the ribs at a joint were exposed to view, as the upper cover plate was not in place. Mr. Kinloch, to whose practical knowledge of bridge work and powers of observation much of the excellence of Mr. McLure's reports is due, states in his evidence that he observed gaps between abutting ribs as great as 1/32 in., due to irregular finish of the planed ends of the chords. In examination of the material in Belair yard the commissioners found irregularities of workmanship which would account for the conditions described above, and, in our judgment, these could have been avoided only by matching the chords together in the shop previous to shipment. The small gaps between abutting ends of chords closed as the pressure on the chords increased, with no result other than producing irregularity of stress, but the lateral deviations had to be corrected by the use of jacks.

As Mr. Cooper in his evidence has expressed the opinion that these lower chord joints were, during erection, the weakest and most hazardous part of the structure and that they suffered from lack of appreciation of the necessary care to be given them, it is advisable to closely review all evidence concerning them. The chords consisted of four deep and narrow ribs latticed together and finished with square ends, so that the pressure might be transmitted from one chord to the next by contact of the abutting ends. Under the system of erection adopted it was possible to place the adjoining chord ends in contact only at either the upper or lower edges, and it was expected that the chords would gradually turn during the settlement of the bridge until the end surfaces came fully in contact, as is more fully described in appendix No. 10. This expectation was realized. The adjoining chords were held together by eight splice plates, an upper and a lower horizontal plate, two vertical plates on each outside rib and one vertical plate on each inner rib. The order of erection required that the lower plates should be put in position before the next chord was set; the vertical plates were next placed, and the erection of the joint was finished by bolting on the upper plate. Owing to the erection angle at the joint it was possible to use full-size bolts on only one horizontal plate and on one edge, either upper or lower, of each vertical plate. The instructions with regard to the bolts were very definite and read as follows: "All bottom chords to have two-thirds of all holes of web splices filled with 1-in. bolting on the outer ribs, and ⅞-in. bolts on the inner ribs, or their equivalent in smaller bolts or drifts. For top splice plate apply rule (1), (this requires that every hole shall be filled with a bolt), and never take off splice plate again, not even while driving rivets in web splices. Bottom splice plate to be bolted with bolts (two-thirds value). While driving rivets in web splices of chords remove bottom splice plate and bolt across flanges temporary angles to keep flanges in place." Owing to the camber openings at the joints, it was found necessary in some cases to use ⅝-in. bolts, as no longer bolts could enter the holes in their erection condition.

The evidence shows that these instructions were carried out, but not with a full appreciation of their importance. Mr. Birks, who was admitted by all witnesses to have been an exceptionally accurate and painstaking inspector, examined all the bolting towards the end of the season of 1906, this examination being made on direction of Mr. Deans, and at the express request of Mr. Reeves, the president of the Phoenix Bridge Co. He reported as follows:

"All bottom chords splices in anchor-arm—top plate full; bottom plate and webs, 67 per cent; all joints bolted as per instructions," and also "all chords in the first five panels of the cantilever-arm top plate full, rest 67 per cent." Mr. McLure's report about bolting has already been quoted, and Mr. Kinloch, in his evidence, states that the Phoenix Bridge Co.'s instructions about bolting were fully obeyed, but that he personally did not pay much attention to the bolting of the bottom cover plate, as he knew that it had to come off during riveting. Beauvais, the riveter, in his evidence, casts some doubts upon the inspectors' reports, and we are of the opinion that the top and bottom cover plates and the splice plates for the outside ribs, all of which could be readily seen by the inspectors, were correctly bolted, but there may have been some cases of insufficient bolting on the inside ribs. Such cases were, we think, rare. It was intended that, as the camber openings closed, the smaller bolts should be taken out and replaced by larger bolts on all outside plates, the inner plates being difficult of access until the bottom cover plate was removed. This idea does not seem to have been followed in practice to any extent, nor is there any evidence to show that the bolting was systematically tightened up, as it worked loose with the adjustment of the structure. The evidence also shows that the bottom cover plates were left off during the whole period of riveting a joint (usually from ten days to two weeks), and that in the case of 7-8I cantilever-arm this plate was off for nearly the whole month of August, 1907. We must therefore conclude that the splice plates at the joints were rather loosely attached and that the importance of rigidity at these points was strangely overlooked.

It should be noted that this system of bolted splices was a necessity, due to the method of erection adopted, but that there was no reason why the end details of the chords and the splice plates themselves should not have been much more strongly and rigidly designed. The erection problem was unique in magnitude, particularly in the camber requirements, and the method followed by the Phoenix Bridge Co. closely corresponds to that in general and successful use on smaller structures. It is open to criticism on theoretical grounds, and it is possible that other engineers might by other design serve the same ends; the problem in its dimensions is so entirely new that there is room for much study and invention in erection methods for great structures.

We know of no reason why the methods adopted cannot be successfully used, but the evidence shows that the Phoenix Bridge Co. failed to appreciate the important influence that end details and splices had on the strength of the chords. Steps were not taken to ensure that the work was so handled that the maximum rigidity consistent with design was secured at these joints. Considering the circumstances, we know of no good reason why the riveting should not have been much further advanced before the great stresses created by the erection of the suspended span were thrown upon the joints. The report of Mr. McLure, on Nov. 10, 1906, shows that all but eight of the forty lower chord joints were then closed and ready for riveting. Mr. Cooper has clearly stated that he did not consider that the erection methods were subject to his control, although the evidence shows that he was frequently consulted about them, both by Mr. Szlapka and by Mr. McLure. The erection problem in this case was of great importance, and the Quebec Bridge Co. did not place their interests under the direct and responsible control of an experienced engineer acting solely on its behalf.

Difficulties developed almost as soon as the erection of the suspended span got well under way. On Aug. 6, Mr. McLure reports as follows:

"New Liverpool, P. Q., Aug. 6, 1907.

"Mr. Theodore Cooper,
"Consulting Engineer,
"45 Broadway, New York City.

"Dear Sir:

"In riveting up the splice between chords 8 and 7 in the west truss of south cantilever-arm we found the condition of the inside ribs at splice as indicated in following sketch: (Drawing No. 30.)

"Owing to the limited space between the two inside ribs, it would be impossible to jack this splice back, and as the condition is not nearly as bad at the top of the splice we have proposed putting a diaphragm between the two inside ribs to cover the first five rivets up from the bottom on each side of the splice, as indicated in red in the sketch above. The splice plates being riveted on the two inside ribs, it will be necessary to cut out and redrive 20 rivets to do this. This provision, together with the top and bottom cover plates, should be sufficient to hold this splice against the thrust due to its being out of line, which thrust when under its maximum compressive stress I estimate at not over 60,000 lb.

"The Phoenixville office is being notified of this plan and if they will approve will wire us. If this also meets with your approval, or if you wish to suggest another way to remedy the difficulty, will you please wire me at St. Romuald, P. Q., care of Phoenix Bridge Co., as the riveting gangs are ready to finish riveting this splice.

"Very truly yours,
(Signed) "N. R. McLure."

Upon receipt of this letter, Mr. Cooper wired the Phoenix Co. as follows:

"New York, Aug. 8, 1907.

"Phoenix Bridge Co.,
"Phoenixville, Pa.

"Method proposed by Quebec for splicing joints of lower 7 and 8 chords is not satisfactory. How did bend occur in both chords?

(Signed) "Theodore Cooper."

and wrote Mr. McLure on Aug. 9 as follows:

"New York, Aug. 9, 1907.

"N. R. McLure, Esq.,
"Insp. for Erection, Quebec Bridge,
"New Liverpool, P. Q.

"Dear Sir:

"Yours of the 6th regarding bent condition of lower 7 and 8 chord joint came yesterday. I wired Phoenix that the proposed method, as sketched by you, for repairing was not satisfactory. Also asked, what you should have reported, how did both these chords get bent?

"In my opinion, these webs can be brought back to proper line by use of 15 to 20 1-in. bolts, threaded at both ends for nuts passing through the two webs of that half of chord. Of course, means must be taken to stiffen the straight web against its bending when the bolts are tightened.

"If necessary, after getting the bent webs in line, to hold them, spacers and possibly some through bolts may be used.

"Some more satisfactory method than the one shown in your sketch must devised.

"Mr. Deans telegraphs that upon Mr. Szlapka's return he will give me fuller facts.

" Yours truly,
(Signed) "Theodore Cooper."

Then the following telegram was received from Mr. Deans:

"Phoenixville, Pa., Aug. 9, 1907.

"Theodore Cooper,
"Consulting Engineer,
"45 Broadway, New York.

"Mr. Szlapka happened to be at bridge site yesterday; expect him home to-morrow with full information concerning chord joint; will then write you fully.

(Signed) "Jno. Sterling Deans.

To which Mr. Cooper replied as follows:

"New York, Aug. 9, 1907.

"John Sterling Deans,
"Chief Engineer, Phoenix Bridge Co.,
"Phoenixville, Pa.

"Dear Sir:

"Your telegram regarding chord joints at hand. The method proposed as sketched by Mr. McLure is not satisfactory, as telegraphed yesterday.

"These bent webs can be pulled back by use of about 15 or 20 1-in. bolts (in 1 1/16-in. holes) threaded at both ends for nuts, passing from the outer to the inner bent web. The outer straight web being stayed in some manner against its bending.

"If the bent webs, after being pulled into line, tend to go back when released from the bolts, stays must be introduced to hold them in position. Possibly it may be necessary to permanently rivet in some of these 1-in. bolts.

"Please let me know what method you propose to use.

"It is a mystery to me how both these webs happened to be bent at one point, and why it was not discovered sooner.

"Very truly yours,
(Signed) "Theodore Cooper."

On Aug. 10, Mr. Deans wrote as follows:

"Phoenixville, Pa., Aug. 10, 1907.

"Theodore Cooper, Esq.,
"Consulting Engineer,
"45 Broadway, New York.

"Dear Sir:

"Splice cantilever chords 7 and 8.

"Mr. Szlapka did not return to-day as expected, but will no doubt be here on Monday, when we will write you at once.

"Yours truly,
(Signed) "Jno. Sterling Deans."

and on 12th Mr. Deans wrote as follows:

"Phoenixville, Pa., Aug. 12, 1907.

"Theodore Cooper, Esq.,
"Consulting Engineer,
"45 Broadway, New York.

"Dear Sir:

"Chord splice south cantilever-arm, 7 L and 8 L.

"Mr. Szlapka reached the office this morning, and I am able to give you information in connection with this one joint.

"All ribs of the chord 7-L have a complete and full bearing on ribs of 8-L. The bend was, no doubt, put in the rib in the shop before facing, and was probably done when pulling the ribs in line to make them agree with spacing of these ribs and the clearance between ribs, called for on the drawing. The bend being on only one rib of one chord, there being a full bearing over the entire rib, all splice plates being readily put in position, we do not think it necessary to put in the diaphragm, suggested by the erection department.

"Please let us hear from you on this subject promptly, and oblige,

"Yours truly,
(Signed) "John Sterling Deans,
"Chief Engineer."

On Aug. 13, in reply to Mr. Deans, Mr. Cooper wrote as follows:

"New York, Aug. 13, 1907.
"John Sterling Deans, Esq.,
"Chief Engineer, Phoenix Bridge Co.,
"Phoenixville, Pa.
"Dear Sir:

"The information regarding chords splice 7 and 8 L is so different from the dimension sketch sent by Mr. McLure, I can take no action on this matter till the exact facts are presented. Please have your resident engineer and Mr. McLure re-examine this joint and send me exact condition of this rib as to the amount of the bends and relation of the bearing surfaces to each other.

"I don't see how one rib being bent only, as stated in your letter, there can be a complete and full bearing of these ribs.

"Neither can I understand how pulling the ribs into line at the shop could bend it out of line.

"I will write Mr. McLure to-day to have a further investigation of this joint and to report as promptly as possible.

"Yours very truly,
(Signed) "Theodore Cooper."

And on the same day Mr. Cooper wrote Mr. McLure:

"New York, Aug. 13, 1907.
"N. R. McLure, Esq.,
"Insp. for Erection, Quebec Bridge,
"New Liverpool, P. Q., Canada.
"Dear Sir:

"Mr. Deans writes me that only one rib at joint 7 and 8 L is bent and still that there is a full and complete bearing, that the bend was no doubt put in the chord in the shop before facing.

"I have asked him to instruct his resident engineer to join with you in making an exact report, with dimensions of the conditions of this joint, with amount of bearing, and if it is a square bearing or askew.

"In reference to the splicing of T-5 and T-50, mentioned in your letter of 10th inst., I do not care to interfere with the regular programme, as I have not followed the various actions of the loadings at different stages, without going into it carefully. I think there will be more compression at these joints with more of the suspended span in place.

"Please report promptly regarding joint 7 and 8 L with all the facts. "Yours truly,
(Signed) "Theodore Cooper."

Mr. Deans wrote Mr. Cooper on the 14th as follows:

"Phoenixville, Pa., Aug. 14, 1907.
"Theodore Cooper, Esq.,
"Consulting Engineer,
"45 Broadway, New York.
"Dear Sir:

"Chord splice 7 and 8 L. Your letter Aug. 13.

"I will have a full and complete report made of this joint by Mr. McLure and Mr. Birks and submit it to you earliest possible moment.

"Yours truly,
(Signed) "John Sterling Deans,
"C. E. C.,
"Chief Engineer."

On Aug. 14th Mr. Cooper received the following letter of the 12th from Mr. McLure:

"New Liverpool, P. Q., Canada.
"Mr. Theodore Cooper,
"Consulting Engineer,
"45 Broadway, New York.
"Dear Sir:

"I beg to acknowledge the receipt of your letter of Aug. 9, and have noted what you say regarding the method of repairing splice between chord 7 and 8 cantilever-arm west truss. We will not do anything with this then until the matter has been arranged between yourself and Mr. Szlapka.

"The reason I did not report at first as to how these chords got bent was because there were many different theories here as to the cause, no one of which I was at that time ready to accept. One thing I am reasonably sure of, and that is that the bend has occurred since the chord has been under stress and was not present when the chords were placed. This being the case the cause of the bend would seem to be the slight overrunning in length of the bent rib in either chord 7 or 8. Owing to the fact that these chords are faced on the rotary machine, the four ribs at once, this would at first seem to be out of the question, but it seems to me that after the first end of a chord has been faced in turning it with the crane to bring the other end into position for facing, it might be possible for one rib to work slightly by the others longitudinally, without being noticed, and in spite of the latticing, and thus cause a slight difference in length. In fact, in taking the opening in the chord splices on the south anchor-arm, it has often been noticed that a considerable variation existed between the openings of the different ribs at the same splice, which difference I was not able to account for except by the above theory, that during transportation, and in the handling before erection, some of the ribs have worked slightly in a longitudinal direction by each other. In the case in question, of course, this must have happened between the time of facing one end and the other. If this is correct, then it will be a pretty hard matter to draw the splice back into the line with bolts, and our idea in suggesting that diaphragm was to prevent this eccentricity from increasing, rather than to correct that already there.

"As I had supposed, the strike in force for the last three days of last week has been settled and work was resumed again this morning. A meeting of the 'union' was held Saturday night and enough of the discontented element had been lost, so that when the matter was brought to a vote the majority were found to be in favor of returning to work under the original agreement. Those who were not in favor of returning to work, however, are now leaving, so that our force is reduced greatly on both sides of the river.

"Since writing the above I have discovered that splice between chords 8 and 9 on west truss of south cantilever-arm is in the same condition exactly as that between 7 and 8, except that the bend is only 5/16 in. instead of ¾ in. at the bottom, and runs out so that on top this rib is in line, as are the other three.

"This is the same rib, and the bend is in the same direction as that reported for the other splice. When it is decided in what way to treat the splice between chords 7 and 8 we will repair that between chords 8 and 9 in a similar manner.

"Yours very truly,
"N. R. McLure."

To this Mr. Cooper replied on Aug. 15 as follows:

"New York, Aug. 15, 1907.
"N. R. McLure, Esq.,
"Inspector of Erection, Quebec Bridge,
"New Liverpool, P. Q., Canada.
"Dear Sir:

"None of the explanations for the bent chord stand a test of logic.

"I have evolved another theory, which is a possible, if not the probable, one. These chords have been hit by those suspended beams used during the erection while they were being put in place or taken down. Examine if you cannot find evidence of the blow and also make inquiries of the men in charge.

"Yours very truly,
(Signed) "Theodore Cooper."

A further report was made by Mr. McLure on Aug. 16:

"New Liverpool, P. Q., Aug. 16, 1907.
"Mr. Theodore Cooper, Consulting Engineer,
"45 Broadway, New York.
"Dear Sir:

"Referring to your letter of the 13th, regarding splice between 8-L and 7-L on south cantilever-arm, you have no doubt by this time received my letter of the 12th instant, giving my theory of the cause of this bend. These conditions are as indicated in my report of Aug. 6 That Mr. Birks, the resident engineer for the Phoenix Bridge Co., reported exactly the same thing in somewhat different language to Phoenixville, but Mr. Deans has evidently taken a different meaning from his report than was intended. He evidently thinks that only one rib of one chord is bent, whereas it is the same rib of each chord, as indicated in the sketch I sent you. There is really nothing to add to the two letters I have already written regarding this bend, except to say that all the four ribs have full bearing on each other, as indicated also in the sketch of Aug. 6. In order to verify our first reports Mr. Birks and I made a careful and more thorough measurement of this splice to-day, both top and bottom, and I am inclosing a blue print of a sketch made as a result of these measurements. It indicates practically the same condition as described in my first letter, except that it is given more in detail.

"As to the cause of this bend, regarding which I wrote you on Aug. 12, Mr. Deans seems to think that it was put in the shops, but that is because he did not understand the conditions existing. Aside from the fact that it would be hardly probable that these two ribs of different chords sections should be bent the same way exactly the same amount in the shops to dimensions ½ in. to ¾ in. less than called for, I am reasonably sure, as I said before, that this condition did not exist before the erection of these chords, as I have personally inspected every member yet erected in this bridge thus far, except the bottom chords of anchor-arm on the cars just before the erection, looking particularly for bends in ribs of compression members, and whenever discovered have taken measurements of the amounts and recorded them. If these ribs then had been this much out of line before erecting it would be well-nigh impossible to miss seeing them. Consequently, the only way the bend could have occurred, it seems to me, is that reported in my letter of Aug. 12.

"I trust that these explanations, with the inclosed sketch, will make the matter entirely clear. Mr. Birks is sending same sketch to Phoenixville to-day.

"Very truly yours,
(Signed) "N. R. McLure."

Mr. Deans also received a copy of this sketch and wrote Mr. Cooper on Aug. 20 as follows:

"Phoenixville, Pa., Aug. 20, 1907.
"Theodore Cooper, Esq., Consulting Engineer,
"45 Broadway, New York.
"Dear Sir:

"We have advice from your field that you received copy of sketch No. 28 giving further details in connection with cantilever chords splice 7-L and 8-L. You will notice that the two chords have a perfect bearing with each other at all ribs, both chords having one bent rib and not one chord only, as we first understood.

"Yours truly,
(Signed) "John Sterling Deans,
"Chief Engineer."

To which Mr. Cooper replied on Aug. 21 as follows:

"New York, Aug. 21, 1907.
"John Sterling Deans,
"Chief Engineer, Phoenix Bridge Co.,
"Phoenixville, Pa.
"Dear Sir:

"I received copy of sketch of joint 7 and 8-L two days ago.

"I wrote Mr. McLure last week telling him none of the theories as to how this bending occurred were logical. That my theory was a blow on this rib after the two sections were in contact and that it probably was done in moving those suspended beams used in erecting. To examine carefully to see if he could find any evidence of this, he has not yet reported; he did report a similar bend at L-8 and 9 west truss in same rib, but of less amount.

"I still believe this bend can be partly removed by use of long bolts, with threads at each end, outer rib being stiffened to prevent its bending. If it can be pulled nearer straight, stays or bolts must be provided to hold it against future movement.

"I cannot consent to let it go without further action, as the rivets in the cover splices would not satisfy the requirements, to my mind. "Yours very truly,
(Signed) "Theodore Cooper."

This letter was acknowledged by Mr. Deans on Aug. 23:

"Phoenixville, Pa., Aug. 23, 1907.
"Theodore Cooper, Esq.,
"Consulting Engineer,
"45 Broadway, New York.
"Dear Sir:

"Joint 7-L and 8-L, south cantilever-arm. Referring to your letter of Aug. 21, I notice you expect to hear again from Mr. McLure. As soon as you have his report kindly let us hear from you again and oblige,

"Yours truly,
(Signed) "Jno. Sterling Deans,
"Chief Engineer."

On Aug. 26 Mr. Cooper wrote the following letter:

"New York, Aug. 26, 1907.
"John Sterling Deans, Esq.,
"Chief Engineer, Phoenix Bridge Co.,
"Phoenixville, Pa.
"Dear Sir:

"Mr. McLure reports that he can find no evidence of the bent ribs having been hit, and does not think they could have been struck. This only makes the mystery the deeper, for I do not see how otherwise the ribs could have been bent.

"When convenient I would like to discuss with Mr. Szlapka the best means of getting these ribs into safe condition to do their proper work.

"Yours very truly,
(Signed) "Theodore Cooper."

This was acknowledged Aug. 27 by Mr. Deans:

"Phoenixville, Pa., Aug. 27, 1907.
"Theodore Cooper, Esq.,
"Consulting Engineering,
"45 Broadway, New York.
Dear Sir:

"Chord splice 7 and 8, cantilever-arm, south side.

"Replying to your letter of Aug. 20, I will have Mr. Szlapka call to see you first opportunity to discuss this question. He will wire you later the day he will be in New York. "Yours truly,
(Signed) "Jno. Sterling Deans,
"Chief Engineer."

This was the last that transpired with regard to the bent ribs at joint 7-L and 8-L, cantilever-arm, and it is plainly indicated that no one except Mr. Cooper looked upon this matter as serious or as indicating any constitutional weakness. It will be noted that the bends at 7 and 8 were reported on Aug. 6, the bends at 8 and 9 discovered on Aug. 12, and that both bends were in the west truss; that previously from time to time chords with ribs more or less wavy had been reported, and Mr. McLure gave it as his opinion that these bends were caused by stress since erection, because he was sure they were straight when erected, while Mr. Deans thought the bends were made in the shop.

While Mr. Deans after Mr. Szlapka's return gives certain information as to the bend in the 7 and 8 splice, Mr. Szlapka states that on his visit to the bridge he did not examine this splice, and further says that during none of his three visits to the bridge did he examine any chords.

Mr. Kinloch states in his evidence that he did not notice the bends at the 7-L and 8-L joints when the bottom cover plate was first removed, and that he felt confident that these distortions took place after the removal of the cover plate.

It seems clear from the above that Mr. Cooper's statement that the delicacy of the joints was not sufficiently appreciated by the Phoenix Bridge Co. is substantiated. Mr. Szlapka was on the ground and made no special examination in the matter, and Mr. Deans endeavored to throw the blame for the distortions entirely upon the shop work. No evidence has been shown to us to prove that Mr. Deans had any grounds for this assertion, and his inspector, Mr. Morris, was in possession of information that indicated that there was no great probability that such an error could have escaped detection. On Aug. 20 Mr. Kinloch discovered that chord 8-R of cantilever arm was bent, and afterwards found that 9-R and 10-R also showed distortion. He called Mr. Birks' attention to this conditon, but neither of them considered it of importance. Mr. McLure was ill and did not see these bends until several days after they were found (Aug. 23), but Mr. Yenser was made aware of them. On Aug. 23 the joint at chords 5 and 6-R of cantilever-arm was found to be off on one center rib ½ in. at bottom, the offset running to nothing at top. Mr. Kinloch visited chord 8-R daily for several days and imagined that the bend was becoming greater, all four ribs being bent, but not alike.

The bend in chord 9-L anchor-arm was discovered about 9.30 A. M., Aug. 27, to have greatly increased, it having been previously noted and being under observation. Owing to the fact that the 25th was a Sunday, and that there was practically no work done on the 26th, it is doubtful whether this chord was examined between the 24th and 27th.

Mr. Kinloch, who made the discovery, in his evidence says:

"Q. Please relate the occurrences following your discovery of the bent chord on Aug. 27?

"A. Immediately after discovering the bend I brought the matter to the attention of Mr. Yenser and Mr. Birks, and with them re-examined both chord A 9-L and several other lower chord members. We did not know what to make of the matter, and then went up to our office and arranged with Mr. McLure to have the deflections of the suspicious chords measured—this measurement which was made by Birks, McLure and myself showed the extent of the deflections; and their cause, and their ultimate result immediately became a matter of very active discussion. Mr. Birks expressed himself definitely as being of opinion that there was no danger and endeavored to persuade me that the bend had always been in the chord. Mr. Yenser and I were uneasy and considered the matter serious, and finally suggested that McLure and Birks should go to New York and Phoenixville for advice. It was considered that the matter could not be satisfactorily explained by telegraph or telephone, and none of us expected immediate disaster. Mr. Birks and Mr. McLure did not welcome our suggestion, saying that they would only be laughed at on arrival, and it was finally agreed to refer the matter of sending to headquarters to Mr. Hoare, who decided in favor of our suggestion. Mr. Hoare visited the bridge on Wednesday, and spent most of the day there. He appeared very anxious that I should abandon my position of being positively convinced that the bend had occurred since the erection of the cantilever-arm was completed, and argued both this and some possible methods of strengthening the chorus by bracing several times with me. I was somewhat excited and much annoyed at the unwillingness of all the engineers to accept my statement of facts, and on both Wednesday and Thursday avoided further discussion of the matter as much as possible. It was understood that Mr. McLure would immediately wire me if Mr. Cooper took a serious view of the situation, but this he failed to do. Mr. Birks, however, told me on the morning of the 29th inst. that he had been advised by 'phone from Phoenixville that they had a record which showed that the bends had been in the chord before it was shipped from Phoenixville, and that he had just advised Mr. Hoare by telephone at the request of Mr. Deans, to that effect."

As soon as the measurements above referred to were made, it was recognized by Mr. Yenser and the inspectors that they were face to face with a crisis. Mr. Yenser announced his intention of stopping erection until he had referred the matter to Phoenixville. The measurements were plotted, and were reported by mail to Mr. Cooper and to Phoenixville, these reports being delivered on the morning of the 29th. Owing apparently to anxiety already existing among the workmen, it was not considered wise to use either telegraph or telephone. As suggested by Mr. Kinloch, Mr. McLure reported the matter fully to Mr. Hoare on the evening of the 27th, the delay of about 12 hours being accounted for by the making and plotting of the measurements and the necessity of using a personal messenger, as it was not wished to report particulars over the telephone. It is clear that Mr. Yenser, Mr. Kinloch and Mr. McLure were very much alarmed, but Mr. Birks could not be convinced that the bends had recently taken place. He knew better than any one else on the work the care with which the calculations and designs had been made, he was familiar with the experience and abilities of the designers, and could calculate that the stresses were then far below the expected maximum. To engineers the force of such reasoning is very great, and we do not consider that the confidence Mr. Birks placed in his superiors was in any way unusual or unreasonable. There was no misunderstanding, however, on his part; he realized that if the bends had not been in the chord before it was erected, the bridge was doomed, and although Mr. McLure had evidence that the bends had increased more than 1 in. in the course of a week, although Mr. Kinloch was positive that the bends had very recently greatly increased, and although Mr. Clark stubbornly maintained that the chord was absolutely straignt when it left Chaudiere yard, Mr. Birks still strove to convince himself that they must have been mistaken. Mr. Hoare evidently concluded that the matter was too serious for him to settle by any offhand decision, and approved Mr. McLure's mission to New York, wisely requiring that he should get all possible facts before leaving, so that Mr. Cooper need not wait for further information on which to base a decision.

The text of Mr. McLure's report of Aug. 27, is as follows:

"New Liverpool, P. Q., Aug. 27, 1907.

"Mr. Theodore Cooper,
"Consulting Engineer,
"45 Broadway, New York.

"Dear Sir:

"I enclose sketches showing condition of bottom chord sections '606—9 L' of south anchor-arm and '621—9 R and 8 R' of south cantilever-arm, as found from measurements made to-day by the Phoenix Bridge Co.'s assistant engineer and myself, by stretching a line from batten plate to batten plate, as indicated on the sketches, and measuring from this line held taut, to each rib, top and bottom. It was noticed this morning that these chords were bent in this manner, as it is very evident to one walking over them, and as it looked like a serious matter, we measured them.

"Although a number of the chords originally had ribs more or less wavy, as I have reported to you from time to time, it is only very recently that these have been in this condition, and their present shape, undoubtedly due to the stress they are now receiving. Only a little over a week ago, I measured one rib of the 9-L chord of anchor-arm, here shown, and it was only ¾ in. out of line. Now it is 2¼ in.

"In the sketches the red indicates straight lines, and black ones the ribs of chords. A top and bottom view is shown in each case. You will note that chords '606—9L' and '621—9-R' have all ribs bent in same direction, while '621 8-R' has its ribs bent in reverse curves. These bends had become so apparent by to-day that the gangs riveting at these points noticed them, and called Mr. Kinloch's attention to them.

"This matter is being reported in this mail, with sketches from the same measurements, to the Phoenixville office, and the erection will not proceed until we hear from you and from Phoenixville.

"Yours truly,
(Signed) N. R. McLure.

Wednesday, Aug. 28, was a day of waiting and uncertainty. Mr. Yenser had changed his mind during the night, and in the morning continued erection. The men were uneasy and alarmed, and the officials were anxiously awaiting instructions from Phoenixville or New York. Mr. Yenser's decision to continue work was laid before Mr. Hoare, upon whom, as chief engineer, the final responsibility for every step taken rested, decided that he had acted wisely. Mr. Hoare makes this clear in the following letters to Mr. Cooper:

"Quebec, Aug. 28, 1907.

"Theodore Cooper, Esq.,
"45 Broadway, New York City.

"Dear Sir:

"I wired you to-day as under:

"Have sent Mr. McLure to see you early to-morrow to explain letter mailed yesterday about anchor-arm chords.

"Also the following message to the Phoenix Bridge Co. Mr. McLure will call to-morrow to explain Birks's letter regarding anchor-arm chords; will see Mr. Cooper first.

"Regarding this matter, I thought it best for McLure to go at once to be able to explain matters and answer questions. He did not have much time for extended investigation before leaving.

"I have been at the bridge all day trying to get some evidence in connection with the bending of the ribs in this chord. Mr. Kinloch noticed it for the first time yesterday, and all inspectors declare that no such pronounced distortion existed a few weeks ago. Mr. McLure made measurements yesterday afternoon and brought them to my house late last night, and stated that the erection foreman hastily concluded that he would not continue erecting to-day, which alarmed me at the time. Upon arriving at the work this morning he thought better of it and decided to go ahead, at the same time asking me if it would be all right. After ascertaining that the effects from moving the traveler ahead and proceeding with the next panel would be so insignificant, I requested him to continue, as the moral effect of holding up the work would be very bad on all concerned, and might also stop the work for this season on account of losing the men. From further investigation during the day I cannot help concluding that the metal received some injury before it was erected, as the corresponding chord in the same panel, and stressed the same, is in good condition. These panels are being stressed to-day, approximately about 7/10ths of their maximum, and it is difficult to believe that this is the entire cause of the distortion. Now and again a rib in certain members is found to be a trifle longer than another, which, when compressed, might cause a trifling kink in it. There are a few examples of this. The chord in question, when being lifted to the cars in the storage yard broke loose from the grips, one end of which fell a distance of 6 ft. on to timber sills; the other end fell a distance of 2 ft. on to a block of eyebars. In falling it fell over on its side, breaking one of its angles on the north end splice and twisting some of the lacing bars, all of which were renewed. After this the inspectors reported the ribs perfectly straight. On account of this chord falling on to two rigid higher points at ends, with no support in the middle but soft material, the conclusion would be that the deflection would be downward; as a matter of fact, the evidence shows that it was in the opposite direction. Since Mr. McLure left, Mr. Birks has made careful examination of the chord, and states that the actual bending commences at the south splice and was not confined entirely to the lengths between the batten plates, where the lacing angles are used. As the foreman and inspectors declare that these defects were not noticeable until recently, perhaps the stress in this chord has made previous defects more pronounced. I thought I would give you the above story from further investigations by to-night's mail to help you to come to some conclusion.

"Yours truly,
(Signed) "E. A. Hoare."

"Quebec, Aug. 29, 1907.

"Theodore Cooper, Esq.,
"45 Broadway, New York City.

"Dear Sir:

"Mr. Birks has just called me up on the telephone from the bridge and states that he has received a message from Phoenixville stating that they have positive evidence that the chord was not straight before it left the shops. This possibly clears up the mystery why the deflection was in the opposite direction to what it should have been, due to its fall in the storage yard. Mr. Birks has wired that information to Mr. McLure at your office. Mr. Birks further stated that he is positive that the chord ribs were more or less out of line when the splice at the south end was riveted up in the bridge.

"Yours truly,
(Signed) "E. A. Hoare."

"Quebec, Sept. 2, 1907.

"Theodore Cooper, Esq.,
"45 Broadway, New York.

"Dear Sir:

"I thank you for replies to all our messages. I am sorry that you are not well and, of course, this appalling disaster has made you feel a thousand times worse.

"Mr. Berger will answer our purpose very well for the present. The investigating commission may find it necessary later to interview you in New York, due notice of which will be given you.

"I wish to correct a misstatement in my letter to you of Aug. 28, which was written late and very hastily, to confirm telegram and conversation with Mr. Birks about the chord under discussion. The statement in my letter as follows: 'Mr. McLure made measurements yesterday afternoon and brought them to my house late last night, and stated that the erection foreman hastily concluded that he would not continue erecting to-day, which alarmed me at the time. Upon arriving at the work this morning he thought better of it and decided to go ahead, at the same time asking me if it would be all right. After ascertaining that the effects from moving the traveler ahead and proceeding with the next panel would be so insignificant, I requested him to continue, as the moral effect of holding up the work would be very bad on all concerned and might also stop the work for this season, on account of losing the men,' is to some extent a misstatement of facts and not clearly stated, due to too much haste, and which I wish now to correct as under:

"Upon arriving at the work that morning the foreman told me that he had considered it during the night and had already moved the traveler forward, asking myself, Mr. McLure and Mr. Birks if we thought that what he had done would do any harm. We all thought that it would not, as they stated it would only add 50 lb. to the square inch to the chord in question. We all thought at the time that to discontinue the work would entirely stop the work for this season, as the men would not wait and would go elsewhere to prepare for the winter. As stated in my last letter, strictly speaking, I did not request the foreman to continue the work, as he had already done so; at the same time we thought there was no immediate danger in adding so small a load. This latter more clearly states the conversation between us, and I am sorry that I have misstated in my hurry, one or two points which would be more or less confusing.

"Yours truly,
"E. A. Hoare."

It was clear that on that day the greatest bridge in the world was being built without there being a single man within reach who by experience, knowledge and ability was competent to deal with the crisis. Mr. Yenser was an able superintendent, but he was in no way qualified to deal with the question that had arisen. Mr. Birks, well-trained and clear headed, lacked the experience that teaches a man to properly value facts and conditions; and Mr. Hoare, conscious that he was not qualified to give judgment, simply assented to the courses of action that had been determined on by Messrs. Yenser and Kinloch and made no endeavor to make a personal examination of the suspected chords.

Some measurements were made to test the stability of the main pier, but no one seems to have thought of testing the span for alignment or levels, and above all to measure the chords again to see if they showed any increase in deflection. Mr. Hoare discussed some means of bracing the chords but decided to postpone action until Mr. Cooper was heard from. At Mr. Hoare's request Mr. Birks inspected the chords A 9-L and the A-L 8-9 joint carefully and his observations tended to reassure both Mr. Hoare and himself, as he thought that he found evidence of original crookedness in the chord.

His report to Phœnixville, which was received on August 30th, reads as follows:

"New Liverpool, Aug. 28th, '07,
"THE PHOENIX BRIDGE COMPANY,
Phoenixville, Pa.

"DEAR SIRS:

"I have made a further investigation of chord 9-A, and beg to report following additional data. The bend in the chord starts at the faced splice at the shore end and not at the edge of the splice batten. It appears from this that at least a large portion of the bend was in the chord when the top and bottom splice battens were riveted early in June. This and the fact that the lacing angles are not disturbed leads me to believe that the ribs were bent before erection in spite of the fact that Mr. Clark and Kinloch think all ribs were straight when the chord was repaired. From the evidence so far, I do not think we are justified in assuming it to be a fact that the ribs of any of the chords have buckled since erection, and Mr. Yenser has come to the same conclusion.

"Yours truly,
(Signed) "A. H. BIRKS."

After he had made his examination, Mr. Birks called Mr. Kinloch and waited at track level, while Mr. Kinloch went down to the chord and checked Mr. Birks' observations. After careful discussion with Mr. Kinloch of what was then done, we are forced to conclude that the sketch in Mr. Birks' letter shows only his personal idea of the shape and extent of the existing distortion and cannot be considered as furnishing data on which to base engineering conclusions, as no actual measurements were taken.

On Aug. 29, Mr. Birks' report of the 27th inst. was received at Phoenixville, and was immediately discussed by Messrs. Deans, Szlapka and Milliken. It was finally decided that it was safe for the work to proceed, and a telephone conversation took place between Messrs. Milliken and Yenser, and another between Messrs. Deans and Birks.

Mr. Szlapka had made some calculations, and Mr. Birks reported his observations of Aug. 28. Messrs. Yenser and Birks were assured that the office approved their action in continuing work of erection, and Mr. Birks was told to tell Mr. Hoare that the bends had been in the chord before they left Phoenixville. This Mr. Birks did (evidence, page 991).

Mr. Deans also telegraphed Mr. Hoare as follows:

Phoenixville, Aug. 29, 1907.
"E. A. HOARE, ESQ.,
"Chief Engineer, Quebec Bridge Co.,
"Quebec, Canada.

"McLure has not reported here; the chords are in exact condition they left Phoenixville in and now have much less than maximum load."

Mr. Hoare had telegraphed to both Mr. Cooper and Mr. Deans on Aug. 28, advising them of Mr. McLure's mission. Mr. Deans has since explained that his telegram did not refer to the chords measured on the 27th inst., but after considering the circumstances we are entirely satisfied that Mr. Hoare was justified in thinking that it did, and in so doing he was confirmed by Mr. Birks' telephone message previously received.

From the time these assurances were received anxiety at the bridge practically ceased, and there is no evidence that any further measurements were made to determine the movements of the suspected chords. As Mr. Hoare expressed it, "I felt quite comfortable that day about it. I knew it could not be long before the matter would be taken up."

Shortly after 11.00 a. m. on Aug. 29, Mr. Cooper reached his office and found Mr. McLure there. After a brief discussion Mr. Cooper wired to Phoenixville as follows:

"New York, Aug. 27, 1907.
"PHOENIX BRIDGE CO., 12:16 P. M.
"Phoenixville, Pa.

"Add no more load to bridge till after due consideration of facts; McLure will be over at 5 o'clock."

This message was received at Phoenixville at 1:15 P. M. Mr. Cooper has explained in his evidence that he was not aware at the time that erection was proceeding, Mr. McLure having advised him to the contrary, and that he telegraphed to Phoenixville instead of to Quebec because he thought action would be more promptly assured by so doing.

Mr. McLure had promised to wire Mr. Cooper's decision to Mr. Kinloch immediately, but he did not do so.

Mr. Deans reached his office about 3:00 P. M. and found Mr. Cooper's telegram there. He arranged for Mr. Szlapka and Mr. Milliken to be on hand to meet Mr. McLure, but otherwise took no action. After Mr. McLure arrived there was a brief discussion, during which Mr. McLure mentioned that he had received a wire from Mr. Birks giving him the result of that gentleman's observations on Aug. 28. It was decided to postpone action until the morning and to await the arrival of Mr. Birks' letter of Aug. 28. This decision was made almost at the minute that the bridge fell.

As a conclusion reached from the evidence and from our own studies and tests, we are satisfied that the bridge fell because the latticing of the lower chords near the main pier was too weak to carry the stresses to which it was subjected, but we also believe that the amount of those lattice stresses is determined by the deviation of the lines of center of pressure, from the axes of the chords, and this deviation is largely affected by the conditions at the ends of the chords. We must therefore conclude that although the lower chords 9-L and 9-R anchor arm, which, in our judgment, were the first to fall, failed from weakness of latticing, the stresses that caused the failure were to some extent due to the weak end details of the chords, and to the looseness or absence of the splice plates arising partly from the necessities of the method of erection adopted, and partly from a failure to appreciate the delicacy of the joints and the care with which they should be handled and watched during erection. We conclude from our tests that owing to the weakness of the latticing, the chords were dangerously weak in the body for the duty they would be called upon to do. We have no evidence to show that they would have actually failed under working conditions had they been axially loaded and not subject to transverse stresses arising from weak ends details and loose connections. We recognize that axial loading is an ideal condition that cannot be practically attained, but we do not consider that sufficient effort was in this case made to secure a reasonable approach to this condition. The Phoenix Bridge Company showed indifferent engineering ability in the design of the joints and did not recognize the great care with which these should be treated in the field.

We consider that Mr. Deans was lacking in judgment and in sense of responsibility when he approved of the action of Mr. Yenser in continuing erection, and when he told Mr. Birks and Mr. Hoare that the condition of the chords had not changed since they left Phoenixville.

No evidence had been produced before the Commission in proof of the correctness of this statement about the chords, and Mr. Szlapka's calculations as stated in the following letter showed that the rivets were even then loaded to their maximum specified stress of 18,000 lbs. per square inch.

"MONTREAL, Jan. 24, 1908.
"PHOENIX BRIDGE COMPANY,
"PHOENIXVILLE, PA.

"GENTLEMEN:

"Will you please file with the Commission a copy of the calculations made by Mr. Szlapka on Aug. 29, 1907, and which are referred to on pages 967 and 968 of the evidence?

"As we are nearing the completion of our report we would esteem it a favor if you would have this information sent to us immediately.

"It is possible that you may not have an exact copy of these calculations, but no doubt they can be duplicated, and Mr. Szlapka's certificate to this effect would be sufficient.

"Truly yours,
(Signed) "HENRY HOLGATE."

"PHOENIXVILLE, PA.
"HENRY HOLGATE, ESQ., Jan. 31, 1908.
"CHAIRMAN ROYAL COMMISSION,
"MONTREAL, CANADA.

"DEAR SIR:

"Replying to your letter of Jan. 24, I enclose herewith letter from Mr. Szlapka of this date, giving calculations similar to that made on Aug. 29 regarding chord 9-L, south cantilever arm.

"Yours truly,
(Signed) "JNO. STERLING DEANS,
"Chief Engineer."

"PHOENIXVILLE, PA., Jan. 21, 1908.
"JOHN STERLING DEANS, ESQ.
"Chief Engineer, The Phoenix Bridge Co.
"PHOENIXVILLE, PA.

"DEAR SIR:

"Referring to Mr. Holgate's letter of Jan. 24, addressed to the Phoenix Bridge Co., I beg to give you below the calculations similar to the one made on Aug. 29, 1907, referring to chord 9-L, south anchor arm.

"Taking 1½ in. as the average reported curvature of chord 8-L, we have:

"$(WL/4) \times 12 = 780^\circ \times 18{,}000 \times 1\tfrac{1}{2}$ in. $= 21{,}060{,}000$ inch-lbs.

"$W/2 = 61{,}600$ lbs.

"Stress in each lattice, $S = 61{,}600 \times 1.4 \div 4 = 21{,}600$ lbs.

"Yours truly,
(Signed) "THE PHOENIX BRIDGE CO.,
"Per P. L. SZLAPKA."

The theory underlying these calculations is very questionable, but it was adopted in the design of the bridge, and we cannot understand why its warning was so entirely disregarded in the face of the consequences that might result.

With reference to Mr. Cooper's telegram, Mr. Deans knew that he was in possession of later information from the bridge than had reached Mr. Cooper and therefore decided to wait for Mr. McLure and afterwards for the arrival of Mr. Birks' letter of August 28th before taking action. The whole incident points out the need of a competent engineer in responsible charge at the site.

Mr. Hoare was the only senior engineer who was able to reach the structure between August 27th and August 29th. He was fully advised of the facts yet did not order Mr. Yenser to discontinue erection which he had power to do; we consider that he was in a much better position than any other responsible official to fully realize the events that had occurred, and his failure to take action must be attributed to indecision and to a habit of relying upon Mr. Cooper for instructions.

We are satisfied that no one connected with the work was expecting immediate disaster, and we believe that in the case of Mr. Cooper his opinion was justified. He understood that erection was not proceeding; and without additional load the bridge might have held out for days.

Our tests have satisfied us that no temporary bracing such as that proposed by Mr. Cooper could have long arrested the disaster; struts might have kept the chords from bending, but failure from buckling and rivet shear would soon have occurred.

(Signed) "HENRY HOLGATE,
"Chairman,
"J. G. G. KERRY,
"J. GALBRAITH."